University of Pardubice
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A DECISION-MAKING MODEL FOR THIRD-PARTY LOGISTICS PROVIDER SELECTION

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Thesis

2021

Ph.D. student

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Study program

P3710 Technique and Technology in Transport and Communications

Field of study

3708V024 Technology and Management in Transport and Telecommunications

Supervisor

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Training workplace

Department of Transport Management, Marketing and Logistics

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Poděkování

Rád bych vyjádřil upřímnou vděčnost svému poradci doc. Ing. Petru Průšovi, Ph.D. za nepřetržitou podporu mého doktorského studia a souvisejícího výzkumu, za jeho trpělivost, motivaci a ohromné znalosti. Jeho vedení mi pomohlo po celou dobu výzkumu a psaní této práce a od koho jsem se toho hodně naučil.

Chtěl bych také poděkovat všem lidem na dopravní fakultě, na katedře managementu, marketingu a logistiky za plnou podporu, pomoc a porozumění.

Konečně, moje hluboká a upřímná vděčnost mé rodině za jejich nepřetržitou lásku, pomoc a podporu.

Stefan Jovčić

Acknowledgement

I would like to express my sincere gratitude to my advisor doc. Ing. Petr Průša, Ph.D. for the continuous support of my Ph. D. study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis and from whom I have learned a lot.

I would like also to thank all the people at the Transport Faculty, at the Department of Management, Marketing and Logistics for full support, help, and understanding.

Finally, my deep and sincere gratitude to my family for their continuous love, help, and support.

Stefan Jovčić

Title

A DECISION-MAKING MODEL FOR THIRD-PARTY LOGISTICS PROVIDER SELECTION

Annotation

The issues such as globalization, fast-changing markets, quality of service, more and more demanding customers, and many others, present some of the crucial challenges of the supply chain for enterprises and organizations.

Given the fact that supply chains are becoming more complex and extensive, it becomes difficult for the company to organize its activities independently to end-users. Therefore, the cooperation between participants in supply chains is of huge importance. Proper selection of partners in the initial phase of the supply chain is an essential issue for both the company and its customers.

This dissertation proposes a decision-making tool for the selection of the company's collaboration partner – a 3PL service provider. The qualitative and quantitative criteria are taken into consideration and the author interviewed more than 15 experts from the logistics and supply chain field.

The first part of the dissertation addresses an issue about the need for 3PL service providers. In other words, it is necessary to help the company decide about the need for 3PL service providers. The second part relates to the 3PL service provider evaluation. Namely, the experts from the field, as well as an extensive review of the literature help the author of this dissertation decide about the identification as well as evaluation of criteria. The third part, where the main contribution may be found, is oriented to the 3PL service provider selection, by suggesting a decision-making tool.

The decision-making tool uses a combination of multi-criteria analysis methods with fuzzy logic. In the beginning, to select the distribution concept, the ARAS multi-criteria analysis method is used. Company considers two possible alternatives. Alternative 1: the distribution concept using its transport fleet and Alternative 2: the distribution concept using 3PL service providers. To identify as well as assess the criteria and alternatives, the experts' opinions are taken into consideration. This is an important issue for companies who need to decide whether to engage 3PL or to do business by themselves. For the case when alternative 2 is a better solution, further continuation of the methodology proposed is to show how to identify the criteria for 3PL selection (in the second phase), how to

evaluate them, and what methods to use in the 3PL selection. Experts' opinions as well as an extensive review of the literature was helpful to identify and evaluate the criteria for 3PL selection. A multi-criteria analysis method (such as AHP) combined with fuzzy logic was used to determine the criteria importance. The obtained criteria weights are used in further multi-criteria analysis method such as TOPSIS, to rank the best 3PL service provider among 25 of them. Since no complete data were available to create a real-life case study, given the time constraints of this research, some hypothetical data are used within this dissertation. The experts confirmed that the input data generated by the author of the dissertation, were close to the real conditions on the market and could be used in the illustrative example form.

Finally, a decision-making tool is proposed based on fuzzy logic. The inputs are previously identified criteria (from the second phase) and the outputs are the preferences obtained by the TOPSIS. To obtain the fuzzy rule base, Wang-Mendel's method is applied. The proposed tool is particularly suitable for the implementation when there is no concrete numerical input data about the criteria, but they are given descriptively, throughout the linguistic statements. Therefore, the fuzzy logic system was set up based on the outputs from the TOPSIS method. The TOPSIS method may be used only when the values are known and crisp, while the proposed model is suitable when the values are given between the intervals and in the case of crisp values.

Keywords

Logistics, 3PL service providers, Outsourcing, Multi-Criteria Decision-Making (MCDM), Fuzzy-Logic, Wang-Mendel, ARAS

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List of Symbols and Abbreviations

3PL – Third Party Logistics

3PRLP - Third-Party Reverse Logistics provider

AHP - Analytic Hierarchy Process

AI – Artificial Intelligence

ANP - Analytic Network Process

ARAS – Additive Ratio Assessment Method

CI - Consistency Index

CR – Consistency Ratio

DEA - Data Envelopment Analysis

EDI – Electronic Data Interchange

ELECTRE – Elimination and Choice Expressing Reality

FIS – Fuzzy-Inference System

FST - Fuzzy Sets Theory

GRA - Grey Relation Analysis

IFS - Intuitionistic Fuzzy Set

MCDA – Multi-Criteria Decision Making

MCGDM - Multi-Criteria Group Decision Making

RFID – Radio Frequency Identification

RI - Random Consistency Index

SAW - Simple Additive Weighting method

TOPSIS - Technique for Order of Preference by Similarity to Ideal Solution

1 Introduction

In recent years, the field of logistics and supply chain management has grown in both complexity and popularity. The 3PL logistics issue has never been as actual as it is in the last decade. Due to rapid changes in technology and the quality of business processes as well, many players appearing in the complex logistics market. Most of those players collaborate with some companies that need to outsource some parts of their businesses. One of the most difficult tasks for the company who is searching for outsourcing is how to evaluate and select the best external business partner for collaboration. Nowadays, freight transport companies are faced with a large number of challenges and obstacles in the process of transporting goods from the point of origin to the point of the destination. In today's world of efficient production, companies choose a mode of transport that will bring the best value for business at the end of the process. In addition, many criteria come into consideration when the evaluation and selection are made, and depending on the needs of the companies, not all criteria are equally important. However, in addition to cost savings, many other criteria such as quality, delivery, safety are taken into consideration. By selecting the most suitable 3PL service provider, a company can greatly save on costs, improve the quality of business as well as maintain existing, and gain new customers.

The main problem in this dissertation is addressed to 3PL service provider selection. In other words, the 3PL selection problem will be considered to contribute to this very demanding field. Given the fact that the problem established is multidisciplinary by nature, it is necessary to combine knowledge from various fields. The idea of this dissertation is to propose a tool for making decisions about the 3PL provider selection, in the case when input numerical data about the criteria that characterize them are not clearly defined.

The doctoral dissertation is organized as follows: Chapter 1 is introductory and the importance as well as the actuality of the 3PL logistics issue is highlighted. An overview of the scientific literature based on the current knowledge in the field is presented in Chapter 2 and it is organized through the four main sub-chapters. In the review of the literature, the author of this dissertation identifies the criteria as well as methods used by various authors in the field to solve the 3PL selection problem. Besides, an extensive review of the literature is done for outsourcing as a part of the third-party logistics. Chapter 3 defines the main objective as well as related tasks of the doctoral dissertation. Chapter 4 deals with methods that should be used to solve the 3PL selection problem. The main contribution of the dissertation may be found in Chapter 5 where a decision-making tool for 3PL service provider selection is modeled. Before the decision-making tool is modeled, the issue about the needs for 3PL services is considered. It is of huge importance to emphasize that the proposed tool is particularly suitable for the implementation when there is no concrete numerical input data about the criteria, but they are given descriptively, through linguistic statements. Finally, Chapter 6 gives some concluding remarks as well as suggestions.

2 Overview of current knowledge

Nowadays, the field of third-party logistics (3PL) is developing rapidly than ever before, and this trend may be seen in both practice and scientific literature. In the last decades, there are numerous articles, which have been appearing in the field of 3PL.

The main purpose of this section is to provide an extensive review of the literature on third-party logistics (3PL) as an outsourcing trend. To be able to identify gaps as well as have a possibility to contribute to this field, it is of vital importance to know the current situation about outsourcing and 3PL as well.

In further continuation of this section, an extensive literature review of the scientific papers in the field will be conducted. Subsection 2.1 gives an insight into the definition, activities and benefits of third-party logistics in general. In Subsection 2.2, an extensive review of the literature on outsourcing logistics may be found. Subsection 2.3 gives an overview based on the criteria for 3PL provider evaluation and selection while Subsection 2.4 encloses a literature review based on the methods used for 3PL provider evaluation and selection.

2.1 Definition, activities and benefits of third-party logistics

The 3PL service providers are of crucial importance in the logistics and supply chain. They appear as a need for companies to outsource their activities. A definition of 3PL Logistics Service Providers differs from author to author.

According to Lieb (1992), Third-Party Logistics (3PL) is using an external company to perform the logistics services, which have traditionally had performed within the organization. On the other side, Bask (2001) introduced the term of Third-Party Logistics as a relationship between interfaces in the supply chain and 3PL providers, where the logistics services are appearing, in a shorter or longer-term relationship, with an objective of effectiveness and efficiency. Banrodt and Davis (1992) simply defined Third-Party logistics as logistics outsourcing.

In the beginning, the Third-Party Logistics (3PL) were transportation companies, carriers, storage companies or forwarding agents, and nowadays they extended their scope of activities.

According to Chen and Wu (2011), Third-Party Logistics services mostly focus their attention on transportation and warehousing and these third-party logistics service providers should have professional experiences in each service.

A list of possible activities of 3PL and related logistics functions are depicted in Fig. 1.

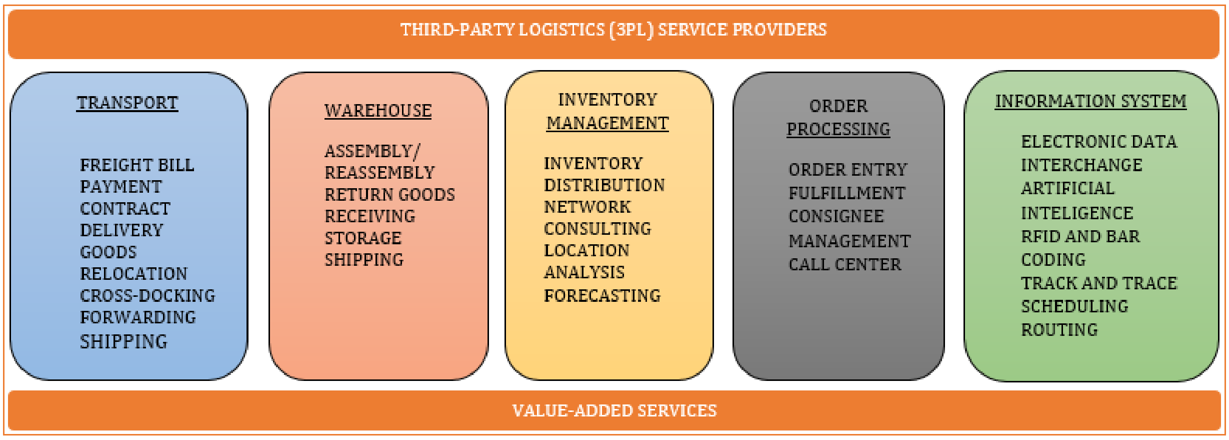

Fig. 1. A list of possible activities of 3PL and their related logistics functions (based on Sink et al., 1996)

In the field of transport, they are responsible for shipping, forwarding, contract delivery, freight bill payment, cross-docking, household goods relocation, etc. In the field of warehousing, they do storage, receiving, (re)assembly, return goods, etc. Regarding inventory management, their function relates to forecasting, location analysis, network consulting, etc. Logistic functions related to order processing are order entry/fulfillment, consignee management, and call center. In the field of the information system, they do Electronic Data Interchange (EDI), routing/scheduling, Artificial Intelligence (AI), Bar Coding (BC), Radio-Frequency Identification (RFID), Web-Based connectivity, Tracking and Tracing (T&T). Value-added activities of 3PL include design and recycling of packaging, marking/labeling, billing, call center activities, and customization.

On the other side, Daugherty et al. (1996) emphasized the list of activities that 3PL logistics service providers should respect:

- dedication to emergency assistance;
- ability to handle changes in the environment;
- flexibility in meeting external needs;
- the ability to propose solutions to potential problems;

- helps the corporation in implementing cost reduction;
- analysis of the problem solution;
- responding to the unforeseen and uncertain needs of operational situations;
- anticipates the transportation problems;
- when unable to provide the services, ensure the countermeasures;

Dittmann and Vitasek (2016) emphasized that, nowadays, 3PL service providers generated a range of benefits for companies who engage them. Such benefits are as follows:

- Reduce transport costs,

- Improve customer satisfaction – on-time delivery and accurate order fulfillment – The best 3PLs have real-time tracking and event management system to provide real-time alerts when delays occur and can respond to change as rapidly and efficiently as possible

- Reduce future costs by leveraging the 3PL's expertise and technology- The best 3PLs use tools such as lean and the latest technology to create continuous improvement, have the most modern warehouse management system, transportation management system, and other system capabilities all of which contribute to greater efficiency. The best 3PLs also possess the most modern network optimization capabilities to select optimal warehouse locations as well as better manage Omni-Channel flows.

- Provide global expertise – this Includes documentation, customs, freight forwarding services, duty optimization, etc.

- Reduce risk – this includes a range of risks such as human risk, environmental risk, and supply chain performance risk

2.2 Review of the literature on outsourcing logistics

Outsourcing as a strategy was first adopted in the 1980s, but as a practice, it was originated in the 1950s (Hätönen and Eriksson, 2009). According to Maltz and Ellram (1997) as well as Razzaque and Sheng (1998), Third-Party Logistics (3PL) is referring to outsourcing logistics. Power et al. (2006) emphasized that the term outsourcing consists of two separate words – "out" and "sourcing", where sourcing refers to the act of transferring work, responsibilities, and decision rights to someone else. Scott-Jackson et al., (2005) as well as Sharma and Loh (2009) agreed that outsourcing was handing over one or many of the business processes to an outside vendor or the utilization of outside available services provided by third-party.

There are some definitions of outsourcing described in the literature by various authors. According to McIvor (2005) outsourcing involves the sourcing of goods and services, previously produced internally within an organization, from external suppliers. Ashley (2008) defined outsourcing as the allocation of risk and responsibility for performing a function or service to another entity. Lynch (2000), as well as Chow and Gritta (2002) emphasized that logistics outsourcing was the process in which a company contracts a third-party (with the necessary experience) to perform reoccurring logistics functions, which could have been provided internally. Sen and Shiel (2006) stated that outsourcing refers to the practice of transferring activities traditionally provided by firms to third-party providers (3PL). Based on the exposed definitions by various authors, the author of this dissertation proposes the following definition of outsourcing: Outsourcing is the transfer of logistics services, mainly transportation, to professionally trained external business partners. All the above-mentioned definitions of outsourcing are presented in Table 1.

Table 1. Definitions of outsourcing by various authors (author)

Author (year)	Outsourcing – definition
Lynch (2000); Chow and Gritta (2002);	The process in which a company contracts a Third-Party to perform reoccurring logistics functions, which could have been provided internally.
McIvor (2005)	The sourcing of goods and services previously produced internally within an organization, from external suppliers.
Ashley (2008)	The allocation of risk and responsibility for performing a function or service to another entity
Sen and Shiel (2006)	The practice of transferring activities traditionally provided by firm to third-party providers (3PL).

Liao and Reategui (2002) stated that one of the main goals of outsourcing was cost savings. Companies have to source out their activities because there are many competitors in the market who can do it cheaper, faster, and better, stated Tayauova (2012). The same author emphasized that flexibility, focus on core activities, cost savings, improving performance, as well as access to experience, are the most important advantages of outsourcing. Regarding the disadvantages, loss of managerial control over outsourced operations, quality problems, the threat to security and confidentiality, hidden costs, and reallocation of existing teams are established as the most important ones. In the study conducted by Somjai (2017), the advantages and disadvantages of outsourcing were exposed. Expertise and fast delivery, concentrating on core process production, risk sharing and cost reduction (operating and recruitment cost) were such advantages, while the disadvantages were the risk of exposing confidential data and technology, synchronizing the deliverables, many hidden costs, and lack of customer focus. Herath and Kishore (2009) emphasized cost reduction as one of the main advantages of outsourcing. The advantages, as well as disadvantages of outsourcing, are presented in Table 2.

Table 2. Advantages and disadvantages of outsourcing (author)

Author (Year)	Outsourcing Advantages	Outsourcing Disadvantages
Tayauova (2012)	flexibility, focus on core activities, cost savings, improving performance, access to experience	loss of managerial control over outsourced operations, quality problems, the threat to security and confidentiality, hidden costs, and reallocation of existing teams
Somjai (2017)	expertise and fast delivery, concentrating on core process production, risk sharing, and cost reduction (operating and recruitment cost)	risk of exposing confidential data and technology, synchronizing the deliverables, many hidden costs and lack of customer focus

When it comes to outsourcing, it is always connected with the risks that companies should accept to deal with. Li-jun (2012) conducted a study on Analysis and Control of Enterprise Logistics Outsourcing Risks, where the risks are classified into several categories such as management risk, contract risk, information as well as a financial risk. According to Leavy (2004) as well as Aron et al. (2005) along with the benefits of outsourcing, the three main risks involved in outsourcing, that should be taken into consideration were the operational risks, strategic risks, and other risks. Kliem (2006) emphasized the possible outsourcing risks: Cost Savings Risk, Financial Risks, Management Complexity, Geopolitical Risk, Internal Employee Issues, Risk of Intellectual Property (IP) Loss, International Data Sharing, Global Cultural Environment, as well as Difficulties in Communication and Coordination. The Outsourcing risks identified by various authors are presented in Table 3.

Table 3. The Outsourcing risks identified by various authors (author)

Author (Year)	Outsourcing risks
Li-jun (2012)	management risk, contract risk, financial risk, information risk and financial risk
Leavy (2004); Aron et al. (2005)	operational risks, strategic risks and other risks

Kliem, R. (2006)	Cost Savings Risk, Financial Risks, Management Complexity, Geopolitical Risk, Internal Employee Issues, Risk of Intellectual Property (IP) Loss, International Data Sharing, Global Cultural Environment and Difficulties in Communication and Coordination

In further continuation, an extensive literature review on various problems being solved in the field of outsourcing logistics will be enclosed. In the last decades, there are many studies in the literature considering multi-criteria decision-making (MCDM) in the form of outsourcing logistics. Besides the multi-criteria analysis methods, many other methods are existing in the field of outsourcing logistics.

According to Mokrini and Aouam (2020), multi-criteria decision analysis (MCDA) methods allow accounting for decision-makers' judgments in evaluating alternatives. They evaluated the risk in healthcare logistics outsourcing in Morocco by using the fuzzy MCDA approach. Liou and Chuang (2010) considered outsourcing provider selection problem by using methods such as DEMATEL, ANP as well as VIKOR. Cheng and Lee (2010) used the ANP method in solving the problem of outsourcing reverse logistics of high-tech manufacturing firms. In their study, the ANP was not only used to investigate the relative importance of reverse logistics service requirements but also to select an appropriate 3PL. Aktas et al. (2011) proposed a descriptive research model to compare the outsourcing perception of the companies in different sectors in Turkey about the motives for outsourcing logistics activities. Based on the statistical analyses, considering 299 companies in Finland, Solakivi et al. (2013) found that cost savings together with flexibility and customer service were the major motives for outsourcing. Hsu et al. (2013) have considered outsourcing provider selection problems in a real case in Taiwanese companies. They used a combination of DEMATEL and ANP methods to solve the problem and instead of ranking the alternatives, applied a modified grey relation theory (GRT) method to select and improve the criterion-gaps.

Kiani et al. (2019) used the Fuzzy-MCDM approach for prioritizing outsourceable activities in universities. To solve the problem, they combined fuzzy logic with many multi-criteria decision-making methods such as AHP, SAW TOPSIS as well as VIKOR. Kahraman et al. (2017) used Fuzzy-AHP and TOPSIS methods for the evaluation of outsourcing manufacturers. Zarbakhshnia et al. (2019) proposed a novel hybrid multiple attribute decision-making method for outsourcing sustainable reverse logistics providers.

The solution to the problem considered is found by applying the Fuzzy-AHP and Grey Multi-Objective Optimization by Ratio Analysis (MOORA-G). Vazifehdan and Darestani (2019) performed a study in the petrochemical industry. The main purpose of their study was to evaluate the components of outsourcing for green logistics using the method of extending the quality performance and decision-making tools with multiple criteria. Bucovetchi et al. (2019) proposed several key performance indicators to assess which of the two options - internal logistics or outsourcing is the best for business performance. Wan et al. (2019) implemented a fuzzy-set qualitative comparative analysis (FSQCA) to examine the drivers of outsourcing decisions in China. Arif and Jawab (2018) considered the impact of the outsourcing strategy on logistics performance in their theoretical study. Pedregosa et al. (2018) pointed out the determinants of success in transport services outsourcing in Europe by using Partial Least Squares Simultaneous Equation Models (PLS-SEM). They proposed the ideal interaction patterns for the structural dimensions that buyer and supplier's companies need to consider to achieve successful outsourcing of transport services.

Pirannejad et al. (2010) used the ANP method for outsourcing decision-making as a multi-criteria problem based on four main dimensions of citizen satisfaction such as accountability, social justice, effectiveness, and efficiency. Chen et al. (2016) carried out a study about the evaluation and selection of the best outsourcing service country in East and Southeast Asia by using an AHP approach. Table 4 elaborates the research mentioned above.

Table 4. Multi-criteria decision-making methods in outsourcing logistics (author)

Authors (Publication year)	**Problem Considered**	**Methods**
Mokrini & Aouam (2020)	Risk evaluation in healthcare logistics outsourcing	Fuzzy MCDA (Fuzzy-AHP, Fuzzy-TOPSIS, Fuzzy-PROMETHEE)
Vazifehdan & Darestani (2019)	Evaluation of the components of outsourcing for green logistics	Fuzzy-ANP, QFD and SIR
Kiani et al. (2019)	Prioritizing outsourceable activities in universities	Fuzzy MCDM (Fuzzy-AHP, Fuzzy-SAW, Fuzzy-TOPSIS, Fuzzy-VIKOR
Zarbakhshnia et al. (2019)	Outsourcing sustainable reverse logistics providers	Fuzzy-AHP and MOORA-G
Bucovetchi et al. (2019)	Key Performance Indicators -in-house or outsourcing	Statistical analysis
Wan et al. (2019)	Drivers of outsourcing decisions	Fuzzy-set qualitative comparative analysis (FSQCA)
Arif and Jawab (2018)	The impact of the outsourcing strategy on logistics performance	Theoretical study – technological consideration

Pedregosa et al. (2018)	Buyer-supplier's interaction in achieving successful transport services outsourcing	Partial Least Squares Simultaneous Equation Models (PLS-SEM)
Kahraman et al. (2017)	Evaluation of outsourcing manufacturers	Fuzzy-AHP and TOPSIS
Chen et al. (2016)	evaluation and selection of the best outsourcing service country in East and Southeast Asia	AHP
Solakivi et al. (2013)	Motives for outsourcing logistics activities	Statistical analysis
Hsu et al. (2013)	Outsourcing provider selection problem	DEMATEL, ANP and GRT
Aktas et al. (2011)	Motives for outsourcing logistics activities	Statistical analysis
Cheng and Lee (2010)	Outsourcing reverse logistics of high-tech manufacturing firms	ANP method
Liou and Chuang (2010)	Outsourcing provider selection problem	DEMATEL, ANP, VIKOR
Pirannejad et al. (2010)	Outsourcing Decision-making of citizen satisfaction	ANP method

At the end of this subsection, after an extensive review of the literature, it may be noticed that this field has been gaining special attention in the last decades. Some basic definitions of outsourcing, advantages and disadvantages, outsourcing risks, different kinds of outsourcing problems as well as the scientific methods used in outsourcing logistics were the subject of this review.

2.3 Review of the literature based on the criteria for Third-Party logistics (3PL) provider evaluation and selection

Nowadays, in the field of logistics, it is difficult to find the right external business partner (3PL service provider), since the number of 3PL providers has increased significantly and continues to grow. The other reason is that there are huge amounts of criteria that characterize 3PL providers and it is not so easy to decide about its evaluation and selection. It is of huge importance to pay attention to the criteria that characterize them. Not all criteria are equally important.

This subsection provides an insight into the criteria used by various authors to solve the problem of 3PL provider evaluation and selection.

In the early nineteens as well as at the beginning of the new millennium, there are research articles that address the 3PL evaluation and selection problem, which implies the fact about the actuality of the problem (Table 5). Ellram (1990) performed a study on supplier selection in strategic partnerships. The criteria such as financial aspects, technological issues, an organizational structure with strategic issues, and other factors are used. Weber et al. (1991) established the criteria with intending to encourage the creation of a long-term partnership between the company and suppliers, as well as to create the possibility of providing sources of supply for the long-term. They divided the criteria to those of great importance (net price, delivery, and quality) and those of little importance (production plants, geographical location, technical abilities, financial position, management and organization, reputation and position in the industry, and historical performance). Dikson (1996) used over 20 criteria in the research that relates to the evaluation of suppliers. He attempted to extend the number of criteria. In his study, a very important factor attributed to the quality, delivery, historical performance, and warranty. Great importance has been assigned to management and organization, operational costs, production plants, technical abilities, net price, financial position, procedural compliance, communication system, reputation and position in the industry, and willingness to do business. Middle importance has assigned to the criteria such as repair services, attitude, impression, packaging still, relations with working staffs, geographical location, previous business, and improvement. The lowest importance has been given to the reciprocal arrangements. Verma and Pullman (1998) conducted a study to analyze the supplier selection process. Customers select suppliers based on the relative importance of different attributes such as price, quality, delivery performance, and flexibility. Their research has indicated that managers pay the most attention to quality as the most important parameter of the supplier, while the delivery and price come after. Birch (2001) used the criteria classified into five different categories: costs, logistics, quality, development, and managing. Vaidyanathan (2005) developed a framework to evaluate third-party logistics based on the following criteria: price, innovation in services, pre and post customer service, and legal contracts. Aktas and Ulengin (2005) conducted a study on outsourcing logistics activities in Turkey. When choosing a 3PL, they considered different criteria, but the general tendency was to choose a 3PL that has a good reputation and/or those with whom it is easy to collaborate. The criteria that they considered were flexibility in user testing, a response in the delivery cycle, ease of cooperation, mutual trust, and information exchange. In the research study about fuzzy measures of supplier evaluation under lean concepts, Tsai (2009) used the criteria such as service quality, reliability of delivery, on-time delivery, pre and post customer service, target market responsiveness, organization capability, price, and geographical coverage. Guneri et al. (2009) considered the supplier selection problem using the criteria such as quality, reputation, the closeness of the relationship with suppliers as well as reliability. The following table gives a structured overview of the criteria in the 3PL field.

Table 5. Review on the criteria for 3PL evaluation and selection from the 90's (author)

Author (Publication year)	**Criteria for 3PL**
Ellram (1990)	financial aspects, technological issues, an organizational structure with strategic issues
Weber et al. (1991)	price, delivery, quality, production plants, geographical location, technical abilities, financial position, management and organization, reputation, and historical performance
Dikson (1996)	quality, delivery, historical performance, warranty, management and organization, operational costs, production plants, technical abilities, net price, financial position, communication system, reputation and position in the industry, willingness to do business, repair services, attitude, impression, packaging, relations with working staff, geographical location, previous business, and improvement
Verma and Pullman (1998)	price, quality, delivery performance and flexibility
Birch (2001)	costs, logistics, quality, development and managing
Vaidyanathan (2005)	price, innovation in services, customer service and legal contracts
Aktas and Ulengin (2005)	flexibility in user testing, the response in the delivery cycle, ease of cooperation, mutual trust, and information exchange
Tsai (2009)	service quality, reliability of delivery, on-time delivery, pre and post customer service, target market responsiveness, organization capability, price, and geographical coverage
Guneri et al. (2009)	quality, reputation, the closeness of the relationship with suppliers, and reliability

Numerous articles may be found in the literature in the last decade (Table 6). Vijavargiya and Dey (2010) considered the criteria such as cost (inland transportation and ocean/air freight), delivery (schedule flexibility), and value-added services (clearing and forwarding and IT- Track and Trace). Yang et al. (2010) conducted the research based on the LSP selection for AIR cargo by considering the criteria such as performances, features, reliability, conformance serviceability, and perceived quality. Kabir (2012), as well as Parthiban et al. (2012), considered quality, cost, and delivery time to solve the problem of 3PL provider selection. On the other side, Cooper et al. (2012), in the research study about the 3PL provider selection used the criteria such as cost, on-time delivery, order accuracy, consistency in invoices, response to a purchase order, orders received, flawless deliveries, frequency of damages in transportation, inventory accuracy, inventory rotation, warehouse efficiency, returns, service level, transportation risk, and warehouse risk.

Rattanawiboonsom (2014) conducted a research where the transportation risk and warehouse risk emphasized as the two main criteria for selecting a third-party logistics provider. Yayla et al. (2015) have considered the problem for 3PL provider evaluation by using fuzzy multi-criteria decision-making methods. Three criteria (with the sub-criteria) are taken into consideration. The first criterion is the development of sustainable relationships, with the following sub-criteria: transportation cost, financial health, provider reputation as well as similar values. The second criterion relates to the quality of service, with the sub-criteria such as on-time delivery, the response in emergency, delivery reliability as well as the quality of dispatch personnel. The third criterion is the continuous improvement with the sub-criteria such as technological sophistication, firm infrastructure as well as optimization capability. Wang et al. (2015) developed an evaluation and selection framework on strategic 3PL provider selection, based on a real case application in China. They considered six criteria (with the sub-criteria): general company consideration (cost, financial position, logistics equipment, staff's quality, market share, geographic location and experience in the industry); capability (optimization capability, IT capability, management capability, responsiveness, and compatibility); quality of service (delivery quality, customer satisfaction, and conflict resolution); development prospect (investment intention, continual improvement, and growth forecasts); guanxi (in China - the system of social networks and influential relationships that facilitate business and other dealings), and environmental performance. Sahu et al. (2015) have proposed a platform for the evaluation and selection of 3PL providers. Nine criteria taken into consideration are quality, delivery, service, production capability, technical capability, business structure, price, strategic factors as well as risk factors. Govindan et al. (2016) researched to develop 3PL provider selection criteria. The criteria developed are service quality, on-time delivery performance, flexibility in operation, cost of services, customer service, logistics information system, financial stability, reputation, geographic location, technological capability, performance history, and human resource policy. Sen et al. (2016) identified the 35 criteria for 3PL provider selection, which have been considered into 7 performance groups: 3PL services, reverse logistics functions, organizational role, user satisfaction, the impact of the use of 3PL, organizational performance criteria as well as IT application. Through the 3PL services, they considered the criteria such as inventory replenishment, warehouse management, shipment consolidation, carrier selection, and direct transportation services. Regarding the organizational performance criteria, they have used the criteria such as cost, quality, time, flexibility, service, and customer satisfaction. Singh et al. (2017) considered the 3PL selection problem in cold chain management. The criteria taken into consideration when they decided about the 3PL selection are transport and warehouse cost, logistic infrastructure and warehousing facilities, customer service and reliability, network management, material-handling capabilities, quality control and inspection, automation of processes, innovation and effectiveness of cold chain processes, IT tracking applications, and tracing as well as the flexibility of processes. Jung (2017) evaluated 3PL service providers considering social sustainability by using the criteria such as price, customized service, philanthropy, average salary, and management policy, whereby the last three criteria are particularly related to social sustainability. Haldar et al. (2017) proposed an evaluation and selection framework for 3PL vendors. The criteria they used in the study are vehicle rejection, driver rejection, the response time of the vehicles, target achieved, flexibility, dedicated fleet strength as well as freight charge per ton per km. Govindan et al. (2017) conducted an integrated decision-making model for the selection of sustainable forward and reverse logistics providers of an Indian Electronic Manufacturing enterprise. They have ranked the providers according to economic, environmental, and social criteria. Garside and Saputro (2017) solved the 3PL provider evaluation and selection for the steel pipe company. Five criteria taken into consideration are financial performance, service level, management, client relationship, and operational performance. Florez et al. (2017) evaluated 3PL suppliers by considering risk. Five criteria taken into consideration are delivery compliance, transportation conditions (risk for raw materials), fleet conditions (technical risk), documentation management (inventory and payment process risk) as well as service quality. Raut et al. (2018) evaluated and selected 3PL providers by using an integrated multi-criteria decision-making approach. The criteria taken into consideration to solve the task of evaluation and selection are as follows: transportation charge per tone per km, fleet capacity, vehicle type and quality (rejection %), driver rejection, the performance of 3PL with the desired output, flexibility, and lead (response) time of the vehicles. Bianchini (2018) conducted a study on 3PL provider selection. The criteria taken into consideration are the costs of service, service level, geographical location, level of professionalism, specific references in the same sector as well as innovation capacity, and collaboration with the customer. Yazdi et al. (2018) conduct a study regarding the best 3PL in the automotive industry.

According to them, the main criteria taken into consideration are IT, profit, human resource, inventory, service, communication, cost, time quality, relationship, flexibility, location, reputation, and professionalism. Sremac et al. (2018), in the research study about 3PL providers, emphasized the criteria such as vehicle fleet condition, financial stability, the professionalization of drivers, transport cost, application of risk mitigation measures, and IT in transport organization, compensation for damages caused during transportation and reliability.

Since sustainability is one of the most important issues nowadays, numerous articles are arising by considering this issue. From the perspective of sustainability, Gardas et al. (2019) evaluated the criteria for 3PL service providers in the pharmaceutical industry. They identified fourteen criteria related to costs (cost of wastage, distribution cost, cost of training), service quality, quality certification, and health safety, technology innovation and IT capability, healthy relationship with employee and customers, agility and flexibility, expansion capacity into health management distribution service, the capability of robust supply network/distribution network, satisfaction level of the employee, environmental certifications, governmental rules, regulations and political stability, financial performance, sustainable eco-friendly process/recycling, availability of cold storage vehicles as well as suitable drivers. Jagannath et al. (2020) evaluated the 3PL providers from a sustainability perspective and identified the economic, environmental, and social criteria to select the best solution (3PL provider). The economic criterion included the following sub-criteria: cost of services, reputation and market position, delivery reliability, technological expertise, and geographical location. Considering the environmental criterion, the following sub-criteria are taken: resource consumption, compliance with International Organization for Standardization (ISO), green distribution strategies and efficient transportation network, environmental protection policies and emission, effluents, and waste generation. Regarding the social criterion, the sub-criteria such as health and safety practices, staff training, equity labor sources, local community influence, as well as compliance with International Labor Organization (ILO) code is considered. Liu et al. (2020) proposed an interactive decision-making method for third-party logistics provider selection under hybrid multi-criteria such as total assets, transport cost, on-time rate, customer satisfaction, personalized service, user compatibility, transport equipment, employee structure, and technology level. Tuljak-Suban and Bajec (2020) approached the logistics provider selection problem using the criteria such as costs (cost of warehousing, cost of inventory management, and additional service costs), services (opening hours, order size and configuration flexibility, the possibility to change order details, shipment errors, product variety, ability to provide added value services, response time, the possibility for temperature control, humidity, historical on-time delivery, and deviations), information technology (transfer of data in real-time, and use of technology (RFID/barcode)), infrastructure (separation of storage areas, handling equipment (electric, gas, diesel), number and characteristics of docks, distance to highway connection), human resources (worker satisfaction, types and quality of communication, and personal relationships with key customers), and risk management (willingness to assume risk, and data security). To solve the 3PL selection problem, Özcan and Ahıskalı (2020) used the following criteria: the speed of responding to offer requests, the operational performance, accessibility to authorized persons, company image, quality, ease of shipment at competitive prices as well as long term relationship.

Table 6. Review on the criteria for 3PL evaluation and selection in the last decade (author)

Author (Publication year)	**Criteria for 3PL**
Yang et al. (2010)	performances, features, reliability, conformance serviceability, and perceived quality
Vijavargiya and Dey (2010)	cost, delivery, and value-added services
Cooper et al. (2012)	cost, on-time delivery, order accuracy, consistency in invoices, response to a purchase order, orders received, flawless deliveries, frequency of damages in transportation, inventory accuracy, inventory rotation, warehouse efficiency, returns, service level, transportation risk, and warehouse risk
Kabir (2012); Parthiban et al., (2012)	quality, cost, and delivery time
Rattanawiboonsom (2014)	transportation risk and warehouse risk
Yayla et al. (2015)	development of the sustainable relationship, quality of service, continuous improvement
Wang et al. (2015)	general company consideration, capability, development prospect, guanxi, environmental performance
Sahu et al. (2015)	Quality, delivery, service, production capability, technical capability, business structure, price, strategic factors as well as risk factors.
Govindan et al. (2016)	service quality, ontime delivery performance, flexibility in operation, cost of services, customer service, logistics information system, financial stability, reputation, geographic location, technological capability, performance history and human resource policy
Sen et al. (2016)	3PL services (inventory replenishment, warehouse management, shipment consolidation, carrier selection and direct transportation services); organizational performance criteria (cost, quality, time, flexibility, service, customer satisfaction)

Singh et al. (2017)	transport cost, warehouse cost, logistic infrastructure and warehousing facilities, customer service and reliability, network management, material-handling capabilities, quality control and inspection, automation of processes, innovation and effectiveness of cold chain processes, IT applications for tracking and tracing,
Jung (2017)	price, customized service, philanthropy, average salary and management policy
Haldar et al. (2017)	vehicle rejection, driver rejection, response time of the vehicles, target achieved, flexibility, dedicated fleet strength, freight charge per ton per km
Govindan et al. (2017)	economic (financial position, assert ownership, optimization capabilities, cost of services, reputation and market position, experience in a similar industry and geographic location); environmental (environmental protection policies, compliance with ISO standard 14,000, green distribution strategies and efficient transportation network, warehousing and green building as well as participation in green initiatives); social (health and safety policies, staff training, compatibility, local community influence and compliance to international labor organization (ILO)
Garside & Saputro (2017)	financial performance, service level, management, client relationship, and operational performance
Florez et al. (2017)	delivery compliance, transportation conditions (risk for raw materials), fleet conditions (technical risk), documentation management (inventory and payment process risk) and service quality
Raut et al. (2018)	Transportation charge, fleet capacity, vehicle type and quality (rejection %), driver rejection, the performance of 3PL with the desired output, flexibility and lead (response) time of the vehicles.
Bianchini (2018)	costs of service, service level, geographical location, level of professionalism, specific references in the same sector, innovation capacity and collaboration with the customer
Yazdi et al. (2018)	IT, profit, human resource, inventory, service, communication, cost, time quality, relationship, flexibility, location, reputation and professionalism.
Sremac et al. (2018)	vehicle fleet condition, financial stability, the professionalization of drivers, transport cost, Information Technologies, damages caused during transportation and reliability
Gardas et al. (2019)	costs (cost of wastage, distribution cost, cost of training); service quality; quality certification and health safety; technology innovation and IT capability; healthy relationship with employee and customers, agility and flexibility; expansion capacity into health management distribution service; capability of robust supply network/distribution network; satisfaction level of the employee; environmental certifications, governmental rules and regulations and political stability; financial performance; sustainable eco-friendly process/recycling; availability of cold storage vehicles and suitable drivers
Jagannath et al. (2020)	**Economic** (cost of services, reputation and market position, delivery reliability, technological expertise, and geographical location), E**nvironmental** (resource consumption, compliance with International Organization for Standardization (ISO), green distribution strategies and efficient transportation network, environmental protection policies and emission, effluents, and waste generation) and **social** (health and safety practices, staff training, equity labor sources, local community influence, as well as compliance with International Labor Organization (ILO) code)

Liu et al. (2020)	total assets, transport cost, on-time rate, customer satisfaction, personalized service, user compatibility, transport equipment, employee structure, and technology level
Tuljak-Suban and Bajec (2020)	**costs** (cost of warehousing, cost of inventory management, and additional service costs), **services** (opening hours, order size and configuration flexibility, the possibility to change order details, shipment errors, product variety, ability to provide added value services, response time, the possibility for temperature control, humidity, historical on-time delivery, and deviations), **information technology** (transfer of data in real-time, and use of technology (RFID/barcode)), **infrastructure** (separation of storage areas, handling equipment (electric, gas, diesel), number and characteristics of docks, distance to highway connection), human resources (worker satisfaction, types and quality of communication, and personal relationships with key customers), and **risk management** (willingness to assume risk, and data security).
Özcan and Ahıskalı (2020)	the speed of responding to offer requests, the operational performance, accessibility to authorized persons, company image, quality, ease of shipment at competitive prices as well as long term relationship

According to an extensive review of the literature, it may be noticed what criteria were used to evaluate and select 3PL providers by various authors and which ones are the most important. Based on that information, the main idea of the doctoral dissertation is to invent and propose a model that will be easy to implement on the one hand, while on the other hand to sublimate all or at least most of the previously mentioned criteria from the source of the literature.

2.4 Review of the literature based on the methods for Third-Party logistics (3PL) provider evaluation and selection

The 3PL service provider evaluation and selection is not so easy task for decision-makers, given the fact that multiple criteria as well as many existing methods ought to be taken into consideration. From the early beginning until now, the researchers have evolved many methods to solve the 3PL evaluation and selection problem. Most of the methods belong to multi-criteria decision-making methods. In addition to multi-criteria analysis methods, many other methods, such as statistical, mathematical programming methods as well as integrated approaches are used.

One of the most often-used multi-criteria analysis methods is the Analytic Hierarchy Process (AHP). Saaty (1980) originally developed this method. After its introduction, the AHP method was widely used in many fields to solve the multi-criteria decision-making problems, where one of those fields is logistics.

Korpela and Touminen (1996) used the AHP to select the best 3PL warehousing in the processing industry. Yahya and Kingsman (1999) used the AHP method to determine the priorities in selecting suppliers. Akarte et al. (2001) proposed a web-based AHP system to evaluate the casting suppliers. Muralidharan et al. (2002) developed a five-step AHP method to rank the suppliers. Liu and Hai (2005) applied AHP to evaluate and select suppliers. So et al. (2006) used AHP to assess the quality of service of suppliers in Korea, while Göl and Çatay (2007) applied AHP to select the best 3PL service provider in a Turkish automotive company. Chan et al. (2007) used the AHP method for the supplier selection problem in the airline industry. Hou and Su (2007) used the AHP method to solve a supplier selection problem in the mass-customization environment. Gomez et al. (2008) proposed a model to evaluate the performance of suppliers by using the AHP method. Hudymáčová (2010) applied AHP in supplier selection. Asamoah (2012) applied the AHP method in a pharmaceutical manufacturing company in Ghana. Hruška et al. (2014) solved a 3PL selection problem by AHP in the production company in the Czech Republic. Jayant and Singh (2015) applied the AHP-VIKOR hybrid MCDM approach for 3PL selection. To solve the 3PL selection problem, Tuljak-Suban and Bajec (2020) upgraded the Analytic Hierarchy Process (AHP) method with the graph theory and matrix approach (GTMA). Aguezzoul and Pache (2020) combined the AHP with the ELECTRE I methodology to solve the 3PL selection problem.

Analytic Network Process (ANP) is also a frequently used method for 3PL evaluation and selection problems. Meade and Sarkis (2002) proposed a conceptual model to evaluate and select a Third-Party Reverse Logistics provider (3PRLP). Sarkis and Talluri (2002) applied ANP to evaluate and select the best supplier taking into consideration 7 evaluating criteria. Bayazit (2006) applied ANP to tackle the supplier selection problem. Jkharkharia and Shankar (2007) applied ANP to select the best logistics service provider. Further research regarding third-party reverse logistics provider (3PRLP) evaluation and selection is proposed by Zareinejad and Javanmard (2013). They applied ANP, Intuitionistic Fuzzy Set (IFS) as well as Grey Relation Analysis (GRA). In their study, the

ANP method is used to identify the most important attributes in the selection and evaluation of 3PRLP.

A Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is one of the most often used methods in third-party logistics. Mostly, this multi-criteria analysis method is used in combination with fuzzy logic, ANP, AHP, DEA, etc. There are a lot of studies in the research literature that may confirm it. Chen and Yang (2011) used limited Fuzzy-AHP and Fuzzy-TOPSIS to select suppliers. Zeydan et al. (2011) used a combination of fuzzy-AHP, fuzzy-TOPSIS, and DEA methods in the automotive industry, to evaluate and select suppliers. Singh et al. (2012) applied the TOPSIS method for supplier selection in the automotive industry as well. Jayant et al. (2014) combined the TOPSIS with AHP to select the reverse logistics service provider in the mobile phone industry. The objective of the study was to develop a decision support system to assist the top management of the company to select and evaluate different 3PRL service providers. Laptate (2015) used fuzzy modified TOPSIS for supplier selection problems in the supply chain.

ELECTRE (ELimination Et Choice Translating REality) is a family of multi-criteria decision analysis methods. Aguezzoul and Pires (2016) used the ELECTRE method for 3PL performance evaluation and selection in a complex strategic decision process that involves various qualitative and quantitative criteria. Before that, Govindan et al. (2010) used the fuzzy-ELECTRE method to rank 3PRL providers. The method was applied to a battery recycling case. Liu et al. (2019) applied an extended multi-criteria group decision-making PROMETHEE method in ABC company, in order to select a third-party provider.

When it comes to the combination of Fuzzy logic with the multi-criteria decision-making methods, there are many studies in the scientific literature. A Fuzzy-AHP method deals with the problems that use the concepts of fuzzy sets theory and hierarchical structure analysis (Cheng, 1997; Cheng et al., 1999). Ayhan (2013) emphasized that basically, the Fuzzy-AHP method represented the elaboration of a standard AHP method into a fuzzy domain by using the fuzzy numbers for calculations instead of real numbers. This method finds its application in various fields. For example, Kilincci and Onal (2011) applied Fuzzy-AHP to select suppliers in a washing machine company. Shaw et al. (2012) combined Fuzzy-AHP and Fuzzy-Objective linear programming to select the best supplier, for developing a low carbon supply chain. Firstly, to determine the weights of the predetermined criteria the Fuzzy-AHP is used. Secondly, the best supplier was determined by using Fuzzy-Objective linear programming. Özcan and Ahıskalı (2020) solved the 3PL service provider selection problem combining the multi-criteria decision-making methods with the linear programming models. Zhang et al. (2004), Zhang and Feng (2007), Göl and Catay (2007) as well as Soh (2010) combined AHP and Fuzzy approaches in solving a 3PL service provider evaluation problem. Cheng et al. (2008) used the Fuzzy-AHP to calculate the relative importance among individual dimensions and sub-criteria on the evaluation of fourth-party logistics (4PL) selection criteria. Arikan (2013) dealt with the Fuzzy-AHP method for multiple-objective supplier selection problems. Rezaeisaray et al. (2016) conducted a study in pipe and fittings manufacturing companies using a novel hybrid MCDM model for outsourcing supplier selection. They concluded that among the selective criteria for outsourcing, business development, focus on basic activities and order delays were the three most important ones. They also ranked suppliers to facilitate decision-making for selection. Sremac et al. (2018) evaluated logistics providers using the Rough SWARA (Step-Wise Weight Assessment Ratio Analysis) and Rough WASPAS (Weighted Aggregated Sum Product Assessment) models. Rough SAW (Simple Additive Weighting), Rough EDAS (Evaluation Based on Distance from Average Solution), Rough MABAC (Multi-Attributive Border Approximation Area Comparison), and Rough TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) were used in the second part of the paper. Zarbakhshnia et al. (2018) proposed a multiple attribute decision-making (MADM) model to rank and select 3PRLPs, using fuzzy step-wise weight assessment ratio analysis (SWARA) to weight the evaluation criteria. To rank and select the sustainable 3PRLPs in the present risk factors, the COPRAS (complex proportional assessment of alternatives) method was used. Jagannath et al. (2020) evaluated and selected the 3PL providers from a sustainability perspective using the interval-valued fuzzy-rough approach.

Some of the statistical methods deal with the 3PL supplier selection problem may be found in the literature. For example, the correlation method was used by various authors (Lai et al., 2002; Sheen and Tai, 2006; Yeung, 2006). Lai (2004) conducts cluster analysis. This kind of analysis analyzes the service capability and performance of logistics service providers. Sinkovics and Roath (2004) used descriptive statistics in 3PL relationships taking into consideration six parameters such as customer orientation, competitor orientation, operational flexibility, collaboration, logistics performance as well as market performance. On the other side, Knemeyer and Murphy (2004) evaluated the performance of 3PL arrangements from the marketing perspective.

Regarding mathematical programming methods (linear and non-linear programming, dual and multi-objective programming, Data Envelopment Analysis (DEA)), various research papers in the field of logistics service providers can be found. For example, Falsini et al. (2012) carried out a study regarding logistic service provider evaluation and selection based on an integration of AHP, DEA, and Linear programming methods. Zhou et al. (2008) used the DEA method to evaluate the efficiency of Chinese 3PL. Hamdan and Rogers (2008) evaluated the efficiency of 3PL logistics operations using the DEA method. Kumar et al. (2006) solved a multi-objective 3PL allocation problem for fish distribution. For better transparency, the aforementioned literature review on the methods for 3PL evaluation and selection is presented in Table 7.

Table 7. Review based on the methods for 3PL evaluation and selection (author)

Author (Publication year)	**Method**
Korpela & Touminen (1996); Yahya & Kingsman (1999); Akarte et al. (2001); Liu and Hai (2005); So et al. (2006); Göl & Çatay (2007); Chan et al. (2007); Hou & Su (2007); Gomez et al. (2008); Hudymáčová (2010); Asamoah (2012); Hruška et al. (2014);	AHP
Sarkis & Talluri (2002); Meade & Sarkis (2002); Bayazit (2006); Jkharkharia & Shankar (2007); Zareinejad & Javanmard (2013);	ANP
Kumar et al. (2006); Zhou et al. (2008); Hamdan & Rogers (2008);	DEA
Govindan et al. (2010)	Fuzzy-ELECTRE method
Chen & Yang (2011);	Fuzzy-AHP and Fuzzy-TOPSIS (Integrated approach)
Zeydan et al. (2011);	Fuzzy-AHP, Fuzzy-TOPSIS and DEA
Singh et al. (2012);	TOPSIS
Falsini et al. (2012);	AHP, DEA and Linear Programming Method
Arikan (2013);	Fuzzy-AHP
Jayant et al. (2014);	AHP-TOPSIS
Jayant and Singh (2015);	AHP-VIKOR
Laptate (2015);	Fuzzy-modified TOPSIS
Rezaeisaray et al. (2016)	DEMATEL, FANP, and DEA
Aguezzoul & Pires (2016);	ELECTRE
Cheng (1997); Cheng et al. (1999); Zhang et al. (2004); Zhang & Feng (2007); Göl & Catay (2007); Cheng et al. (2008); Soh (2010); Kilincci & Onal (2011); Shaw et al. (2012); Ayhan (2013); Arikan (2013);	Fuzzy-AHP and Fuzzy-Objective linear programming (Integrated approach)

Lai et al. (2002); Sinkovics & Roath (2004); Knemeyer & Murphy (2004); Sheen & Tai (2006); Yeung (2006); Lai (2004);	Statistical Methods
Sremac et al. (2018);	Rough SWARA, Rough WASPAS, Rough SAW, Rough EDAS, Rough MABAC, Rough TOPSIS
Zarbakhshnia et al. (2018);	SWARA, COPRAS
Tuljak-Suban & Bajec (2020)	AHP method with the Graph Theory and Matrix Approach (GTMA)
Aguezzoul & Pache (2020)	AHP-ELECTRE I
Özcan & Ahıskalı (2020)	MCDM-Linear programming
Jagannath et al. (2020)	Interval-valued fuzzy rough approach

Based on an extensive review of the literature in the field of third-party logistics, it may be noticed, what kind of methods were used by various authors to solve the problem of evaluation and selection. The most often used methods are the multi-criteria decision-making methods in combination with fuzzy logic. Nowadays, in order to support the 3PL evaluation and selection process, there are many newer multi-criteria methods, such as SWARA, EDAS, MACBAC, WASPAS that are based on group decision-making in a fuzzy environment.

The overview of the literature has revealed that there is no decision-making tool to decide on the needs for the 3PL services. Besides, the Fuzzy Inference System (FIS) has not been used before to evaluate and select 3PL service providers. Therefore, in this thesis, a novel decision-making tool that unites several MCDM methods and FIS into a single methodological framework will be formulated. Moreover, the novel decision-making tool will be able to easily outline the needs for 3PL services and efficiently evaluate and select 3PL providers.

The theoretical explanation of the methods, supposed to be used in the dissertation, will be presented in Chapter 4, while the main objective with tasks for its fulfillment will be given in Chapter 3.

3 The main objective of the doctoral dissertation

The 3PL selection problem is an actual issue nowadays as confirmed in the previous research provided in Chapter 2. Bearing that fact in mind, it is necessary to contribute to this field by inventing a decision-making tool for 3PL provider selection.

The main objective of the doctoral dissertation is to propose a decision-making tool that can help decide about the 3PL service provider selection. That kind of tool is supposed to be understandable as well as easy for implementation.

The intention of this tool is to help decide about the best 3PL provider solution in the circumstances when there is no precise information about input values related to the criteria or they cannot be expressed as crisp values. The novelty of the thesis is its ranking of the 3PL service providers on the economic, safety, environmental, technological, and social dimensions that is of crucial importance for the sustainability of the logistics industry and global society.

In order to fulfill the objective of the research, it is necessary:

- to analyze the current situation in the field of third-party logistics (3PL),
- to determine the possibility of improvement in the field of 3PL evaluation and selection.
- to develop a new preference model for the 3PL provider selection
- to apply the proposed model to the illustrative example

In order to be effectively accomplished the complex tasks highlighted in the doctoral thesis, it is necessary to apply the knowledge from a number of different areas, given the fact that the problem is multidisciplinary. These areas cover logistics theory, fuzzy logic theory, multi-criteria decision-making, programming, and some parts of operational research.

4 Overview of the methods used in the dissertation

This chapter provides an insight into the methods used in the doctoral dissertation. Given the fact that the 3PL selection problem needs to take into consideration multiple criteria, the multi-criteria analysis methods such as ARAS, AHP as well as TOPSIS will be used. All of these methods will be combined with fuzzy logic, which deals with insufficiently precise data.

4.1 Multi-criteria analysis

In recent years, the multi-criteria analysis methods gain special attention from various authors and it may be seen by numerous studies. The multi-criteria analysis methods provide great assistance in various management actions of the most diverse systems. According to Pedrycz et al. (2011), a multi-criteria decision-making problem can be interpreted as a decision-making problem, where a set of experts, individuals or decision-makers try to reach a common solution by expressing their opinions, preferences about a set of alternatives in the presence of a set of criteria. Therefore, the multi-criteria analysis aims to compare different actions or solutions according to a variety of criteria and policies.

4.1.1 Additive Ratio Assessment (ARAS) method

The Additive Ratio Assessment (ARAS) method is one of the relatively new multi-criteria decision-making methods developed by Zavadskas and Turskis (2010). This method is very efficient and easy to use in situations where multiple criteria are taken into consideration. Although the ARAS method is a new approach in the MCDM literature, it has been applied in many areas. Such areas are as follows: built and human environment renovation (Tupenaite et al., 2010), logistics center location (Turskis and Zavadskas, 2010a), supplier selection problem (Turskis and Zavadskas, 2010b), foundation installment (Zavadskas et al., 2010), built heritage projects (Turskis et al., 2013), personnel selection (Keršulienė and Turskis, 2014), historic buildings preservation (Kutut et al., 2014), brand extension strategy selection (Zamani et al., 2014), transportation company (Radović et al., 2018), renewable energy systems (Ghenai et al., 2020), etc.

According to Zavadskas and Turskis (2010), the ARAS method can be described through several steps:

Step 1. Formulate a decision-making matrix (DMM)

A decision-making matrix consists of m feasible alternatives (rows) rated on n sign full criteria (columns).

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}; i = \overline{0,m}, j = \overline{1,n}; \quad (1)$$

where: m - number of alternatives, n – number of criteria describing each alternative, x_{ij} – value representing the performance value of the i–th alternative in terms of the j-th criterion, x_{0j} – optimal value of j-th criterion.

If the optimal value of j-*th* criterion is unknown, then:

$x_{0j} = max_i x_{ij}$, if $max_i x_{ij}$ is preferable;

$x_{0j} = min_i x_{ij}^*$, if $min_i x_{ij}^*$ is preferable; (2)

Usually, the performance values x_{ij} and the criteria weights W_j are considered as the entries of a DMM. The system of criteria, as well as values and initial weights of criteria are determined by experts. The information can be corrected by the interested parties by considering their goals and opportunities.

Step 2. Normalize the input data

In this step, the initial values of all the criteria are normalized – defining values $\overline{x_{ij}}$ of normalized decision-making matrix $\bar{X}$.

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}; i = \overline{0,m}, j = \overline{1,n}; \quad (3)$$

For the criteria with the maximal preferable values, the normalization is done by the following equation:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}};\tag{4}$$

For the criteria with the minimal preferable values, the normalization is done through two-steps, by the following equation:

$$x_{ij} = \frac{1}{x_{ij}^{*}}; \bar{x}_{ij} \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}};\tag{5}$$

Step 3. Define normalized-weighted matrix - $\hat{X}$

It is possible to evaluate the criteria with weights 0 < W_j < 1. Only well-founded weights should be used because weights are always subjective and influence the solution. The values of weight W_j are usually determined by the expert evaluation method. The sum of weights W_j would be limited as follows:

$$\sum_{j=1}^{n} w_j = 1;\tag{6}$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; i = \overline{0, m}, j = \overline{1, n};\tag{7}$$

Normalized-weighted values of all the criteria are calculated as follows:

$$\hat{x}_{ij} = \bar{x}_{ij} \cdot W_j ; i = \overline{0, m};\tag{8}$$

where W_j is the weight (importance) of the *j-th* criterion and $\bar{x}_{ij}$ is the normalized rating of the *j-th* criterion.

Step 4. Determine value of optimality function

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij};\ i = \overline{0, m};\tag{9}$$

where S_i is the value of optimality function of *i-th* alternative.

The biggest value of S_i is the best one, while the least one is the worst. Therefore, the greater the value of the optimality function S_i, the more effective the alternative. The priorities of alternatives can be determined according to the value S_i.

Step 5. Calculate the degree of the alternative utility

To calculate the degree of the alternative utility, it is necessary to compare the variants with the ideally best one S_0. The calculation of the utility degree K_i of an alternative a_i is given below:

$$K_i = \frac{S_i}{S_0}; i = \overline{0, m}; \tag{10}$$

where S_i and S_0 are the optimality criterion values, obtained from equation (9). The calculated values K_i are between 0 and 1.

4.1.2 TOPSIS method

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis tool that was originally developed by Hwang and Yoon (1981) and Hwang et al. (1993). Alternatives of the TOPSIS method are evaluated based on their distance concerning the ideal and anti-ideal solution. The alternative is considered the best if there is a minimal distance to the ideal solution and the greatest distance from the anti-ideal solution. Fig. 2 is a spatial distribution of alternatives defined by two criteria of the max type. With A+ and A- respectively, ideal and anti-ideal solutions are marked.

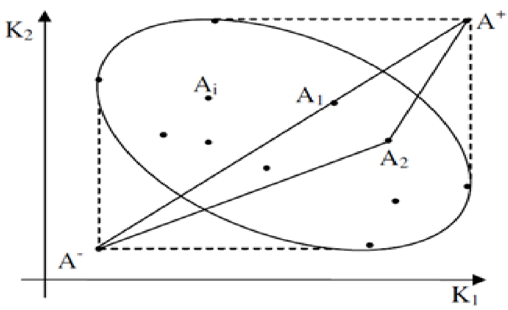

Fig. 2. Alternative distance from ideal and anti-ideal solution (Dimitrijević, 2017)

The symbols A_1, A_2, A_m are alternatives from which the best should be selected, while labels K_1, K_2,…K_n are the criteria which impacts the selection procedure. X_{ij} represents the value of the *i*-th alternative according to the *j*-th criterion. Marks max/min indicate the type of criteria, that is, certain criteria should be maximized, while others should be minimized. W_1... W_n denote the weight of the criteria or their significance. According to Dimitrijević (2017), the TOPSIS method is based on the following steps:

The first step is data normalization, i.e. the reduction of input data to an interval of values 0 to 1. The normalization is done based on the following equation:

$$R = r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^{2}}} \tag{11}$$

where R is a normalized matrix and r_{ij} is normalized data.

The next step is the multiplication of normalized data with normalized weight of the criteria based on the following equation:

$$V_{ij} = W_j' \cdot r_{ij} \tag{12}$$

Whereby W_j' is obtained in the following way:

$$W_j' = \frac{w_j}{\sum_{j=1}^{n} w_j} \tag{13}$$

Based on the obtained values from the previous step, the following step is the formulation of the above-mentioned ideal and anti-ideal solution (A^+ and A^-). A^+ represents the ideal solution, which has all the best characteristics of all the criteria, and A^- is an anti-ideal solution that has all the worst characteristics of all criteria. This is obtained by equations 14 and 15:

$$A^+ = \left\{\left(\max_i V_{ij}, j \in K'\right) \middle| \left(\min_i V_{ij}, j \in K''\right)\right\} = \left\{V_1^+, V_2^+, \dots V_j^+, \dots V_n^+\right\}, (i=1 \dots m); \tag{14}$$

$$A^- = \left\{\left(\min_i V_{ij}, j \in K'\right) \middle| \left(\max_i V_{ij}, j \in K''\right)\right\} = \left\{V_1^-, V_2^-, \dots V_j^-, \dots V_n^-\right\}, (i=1 \dots m); \tag{15}$$

K' represents a subset of the K set, which consists of criteria of max type and K'' represents a subset of the K set, which consists of criteria of min type.

In the next step, the Euclidean distance of each alternative from the ideal and anti-ideal solution is counted:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} ; (i=1 \dots m); \tag{16}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} ; (i=1 \dots m); \tag{17}$$

where S_i^+ represents the distance of the i-th alternative from an ideal solution and S_i^- represents the distance of the i-th alternative from an anti-ideal solution.

After this step, the relative closeness of the alternative to the ideal solution is obtained based on the equation (18):

$$C_i = \frac{S_i^-}{S_i^- + S_i^+},\ [0 \le C_i \le 1]; \tag{18}$$

4.1.3 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is the most widely used multi-criteria analysis method. The AHP was designed by Saaty (1980).

AHP method presents a practical tool to support a decision-making process, a systematic method for comparing a list of criteria or alternatives. The AHP is specifically designed to be used by practitioners themselves, although technical help may be required for large and complex problems. Furthermore, the AHP may be used with many types of data, including judgments based on the experience. The problem considered by AHP may be schematically presented (Fig. 3).

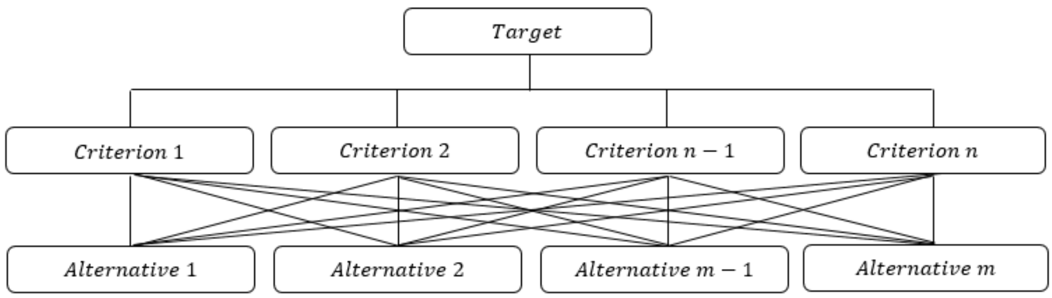

Fig. 3. General hierarchy structure of AHP (based on Saaty, 1980)

To solve a decision-making problem, it may be presented in a form of a comparison matrix (Table 8), where C_i represents the *i-th* Criterion $(i = 1 \cdots n)$, A_j represents the *j-th* Alternative $(j = 1 \cdots m)$, while c_{11} … c_{nn} are the criteria assessments according to Saaty's scale .

Table 8. Comparison matrix (based on Saaty, 1980)

Criteria	C_1	C_2	…	C_n
C_1	c_{11}	c_{12}	…	c_{1n}
C_2	c_{21}	c_{22}	…	c_{2n}
…	…	…	…	…
C_n	c_{n1}	c_{n1}	…	c_{nn}

According to Saaty (1986), Alophance (1997) and Harker (1987), the AHP is based on the following axioms:

1) *Axiom of reciprocity.* If element A is n times more significant than element B, then element B 1/n times is more significant than element A.

2) *The axiom of homogeneity.* The comparison makes sense only if the elements are comparable;

3) *Axiom of dependence.* A comparison is made between the groups of elements of one level concerning the higher-level element, i.e. comparisons at a lower level depending on the higher-level element.

4) *Expectation axiom.* Any change in the structure of the hierarchy requires re-calculation of priorities in the new hierarchy.

The Saaty's scale for evaluating alternatives is presented in Table 9.

Table 9. Saaty's scale for evaluating alternatives (Saaty, 1980)

Note	Definition	Explanation
1	The same meaning	Two elements are identical in meaning to target
3	Poor Dominance	Experience or judgment slightly favors one element in relation to the other
5	Strong dominance	Experience or judgment considerably favors one element in relation to the other
7	Demonstrated dominance	The dominance of one element confirmed in practice
9	Absolute dominance	Highest degree of dominance
2,4,6,8	Among the values	Compromise needed or further division

For example, if there are three criteria, the relationships between them can be described in Table 10.

Table 10. Example of using Saaty's scale (author)

Criteria	C_1	C_2	C_3
C_1	1	5	1/3
C_2	1/5	1	2
C_3	3	1/2	1

After evaluating the criteria, the next step is to normalize data. It means that data need to be into an interval between zero and one. After the normalization of data, it is obligatory to count the sum of each column and then divide each column by the corresponding sum. From the obtained values, it is necessary to find average values by each row and it presents the criteria weights. The obtained weights are pretended to be used in summing the measures as required in the evaluation of the objective hierarchy. The criteria weights are shown in Table 11.

Table 11. Normalization and determination of the criteria weights (author)

Criteria	C1	C2	C3	Criteria	C1	C2	C3	Weights
C1	1	5	1/3	C1	0.181	0.769	0.100	0.345
C2	1/5	1	2	C2	0.036	0.153	0.600	0.262
C3	3	1/2	1	C3	0.857	0.076	0.300	0.411
Σ	5.50	6.50	3.33					

4.1.4 Method for consistency checking

The method for checking consistency is being used to verify the correctness of the estimation for a particular type of problem. In many cases, a person is inconsistent in the assessment of qualitative elements. If the matrix of the experts' assessment can be consistent, it leads to greater reliability in the decision-making process. If there would be a possibility to precisely determine the values of the weight coefficients between all the elements that are compared to a given level of the hierarchy, the own values of the matrix would be completely consistent. However, to the extent that it is claiming that the criteria are not the same between each other, then there is inconsistency, and the reliability of the accuracy of the results decreases. The degree of consistency is calculating by using the equation:

$$CR = \frac{CI}{RI}; \tag{19}$$

Where CR – Consistency Ratio (the degree of consistency); CI - Consistency Index; RI - Random Consistency Index;

The Consistency index (CI) is calculated by the following equation:

$$CI = \frac{\lambda_{max} - 1}{n-1} \tag{20}$$

Where λ_{max} - the own value of the matrix of comparison,

The closer λ_{max} to the number of criteria, the minor inconsistency. In order to obtain λ_{max} it is necessary to multiply the initial comparison matrix with the vector of the coefficient weight and in this way a vector „p“ may be determined. By dividing the vector „p“ with the coefficient weights (W_1, W_2 ... W_n), the matrix of $\lambda(\lambda_1, \lambda_2,...\lambda_n)$ is obtained. λ_{max} may be calculated by the following equation:

$$\lambda_{max}=1/\text{n} \sum_{n=1}^{n} \lambda\ i; \tag{21}$$

The Random Consistency Index (RI) defined by Saaty (1980) and it is shown in Table 12.

Table 12. Satty's scale of Random Consistency Index (RI) (Saaty, 1980)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If the value of the Consistency Ratio is lesser than 10% or equal, the consistency is acceptable. If the Consistency Ratio is higher than 10%, the subjective judgment needs to be revised.

4.2 Fuzzy logic

Zadeh (1965) proposed the fuzzy logic theory. A fuzzy logic theory has further been evolving and expanding until now. Fuzzy logic is gaining significance by introducing the motion of degree in the status verification. In fuzzy logic, the condition for judgment may not be true or false, but allows judgment based on inaccurate and vaguely defined information. Klir and Yuan (1995) emphasized that the issue of uncertainty, within the scientific community, have not always been embraced, from a historical point of view. Based on the mathematical theory of fuzzy sets, which is a generalization of the classical set theory, fuzzy logic represents an extension of Boolean logic.

According to Mendel (1995), a fuzzy logic system is a non-linear mapping of the output data vector into a scalar output. Sarkar et al. (2012) emphasized that fuzzy logic could be successfully used to model situations in which people make decisions in so complex environment where it is very hard to develop a mathematical model.

According to Dernoncourt (2013), one advantage of fuzzy logic to formalize human reasoning is that the rules are given in the natural language. As it was seen in the previous sections, many studies use fuzzy logic to solve various problems, especially a combination with multi-criteria decision-making methods. Voskoglou (2015) stated that fuzzy numbers play a fundamental role in fuzzy mathematics, analogous to the role played by the ordinary numbers in classical mathematics. He defined a fuzzy number as a special form of fuzzy sets on the set R of real numbers. When it comes to fuzzy numbers, there are different types of them such as Triangular, Trapezoidal, Gaussian as well as generalized bell-shaped.

4.2.1 Triangular fuzzy numbers

According to Shyamal and Pal (2007), triangular fuzzy numbers are often used in applications, due to the presence of uncertainty in many mathematical formulations in different branches of science and technology. Triangular fuzzy number is shown in Fig. 4.

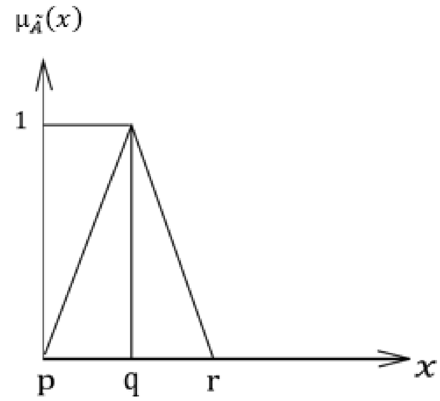

Fig. 4. Triangular fuzzy number (adjusted based on Zadeh, 1965)

Triangular fuzzy numbers are designated as $p_{ij}, q_{ij}, r_{i,j}$.

where: p_{ij} represents the smallest possible value, q_{ij} represents the most suitable (precise) value and $r_{i,j}$ represents the highest possible value. A fuzzy number in the set of real numbers R is a triangular fuzzy number, if its function is $\mu_{\tilde{A}}(X)\ R \rightarrow [0, 1]$, and equal to the following:

$$\mu_{\tilde{A}}(X) = \begin{Bmatrix} \frac{x-p}{q-p},\ p \leq x \leq q \\ \frac{r-x}{r-q}, q \leq x \leq r \\ 0\ , \quad other \end{Bmatrix}; \tag{22}$$

The mathematical operations of triangular fuzzy numbers $\hat{T}_1 = (p_1, q_1, r_1)$ and $\hat{T}_2 = (p_2, q_2, r_2)$ modified are based on Voskoglou (2015), in a following way:

1) Adding two fuzzy numbers:

$$\hat{T}_1 + \hat{T}_2 = (p_1, q_1, r_1) + (p_2, q_2, r_2) = (p_1 + p_2, q_1 + q_2, r_1 + r_2); \tag{23}$$

2) Subtraction two fuzzy numbers

$$\hat{T}_1 - \hat{T}_2 = (p_1, q_1, r_1) - (p_2, q_2, r_2) = (p_1 - p_2, q_1 - q_2, r_1 - r_2); \tag{24}$$

3) Multiplication two fuzzy numbers

$$\hat{T}_1 x \hat{T}_2 = (p_1, q_1, r_1)x(p_2, q_2, r_2) = (p_1 p_2, q_1 q_2, r_1 r_2); for\ p_1 p_2 > 0, q_1 q_2 > 0, r_1 r_2 > 0; \quad (25)$$

4) Division two fuzzy numbers

$$\frac{\hat{T}_1}{\hat{T}_2} = \frac{(p_1,q_1,r_1)}{(p_2,q_2,r_2)} = (\frac{p1}{p2}, \frac{q1}{q2}, \frac{r1}{r2}); for\ p_1 p_2 > 0, q_1 q_2 > 0, r_1 r_2 > 0; \quad (26)$$

5) Reciprocal value two fuzzy numbers

$$\hat{T}^{-1} = (p_1, q_1, r_1)^{-1} = \left(\frac{1}{r_1}, \frac{1}{q_1}, \frac{1}{p_1}\right); \quad (27)$$

4.2.2 Fuzzy Inference Systems (FIS)

In the decision-making process, one of the powerful tools that are effectively used by decision-makers is the fuzzy inference system. The fuzzy inference system is one of the most important units of the fuzzy logic system and the main purpose of this system is According to Kala (2016), Fuzzy Inference Systems (FIS) take inputs and process them based on the pre-specified rules to produce the outputs. Both the inputs and outputs are real-valued, whereas internal processing is based on fuzzy rules and fuzzy arithmetic. On the other hand, Kalogirou (2014) defined fuzzy inference as a method that interprets the values in the input vector and based on some sets of rules, assigns values to the output vector. In fuzzy logic, the truth of any statement becomes a matter of a degree. Mamdani-type (1997), as well as Sugeno-type (1985), represent the two main types of FIS. Fuzzy Inference System, i.e. fuzzy logic controller can be schematically described as in Fig. 5.

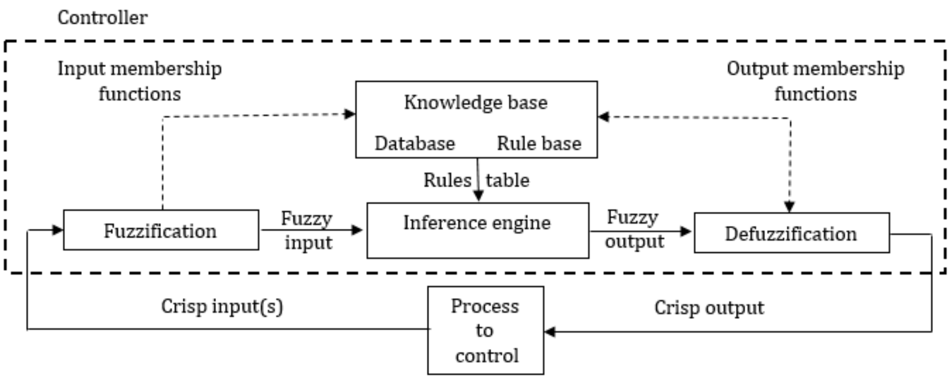

Fig. 5. Basic concept of fuzzy logic controller (Zadeh, 1973)

4.2.2.1 Membership functions

The membership functions can be divided into the input and output membership functions. The inputs are described in terms of linguistic variables, for example, very high, high, ok, low, and very low as shown in Fig. 6.

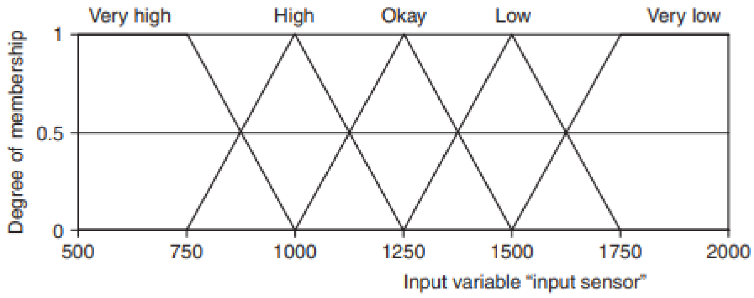

Fig. 6. Membership functions for linguistic variables describing an input (Kalogirou, 2014)

The output can be adjusted correspondingly, according to some membership functions (Fig. 7).

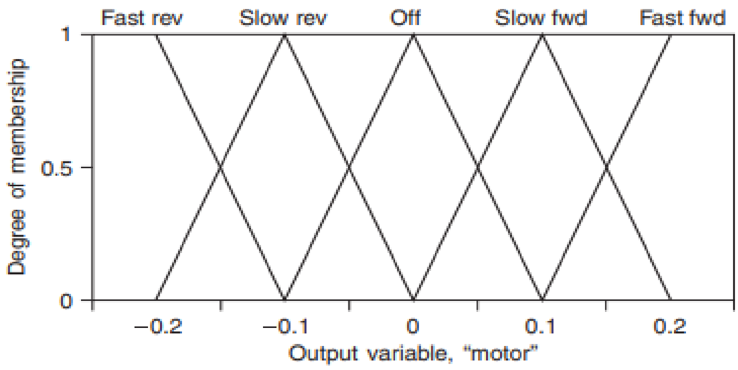

Fig. 7. Membership functions for linguistic variables describing motor operation (Kalogirou, 2014)

According to Zadeh (1973), a design of such a controller contains the following steps: Define the inputs and the control variables; Define the condition interface; Inputs are expressed as fuzzy sets; Design the rule base; Design the computational unit; Determine the rules for defuzzification, i.e., to transform fuzzy control output to crisp control action.

The main purpose of fuzzy rules is to describe the relationship between variables in linguistic terms. One of the well-known methods for obtaining the fuzzy rules is Wang-Mendel's method, which will be more extensively elaborated in the following chapter.

4.2.3 The Wang-Mendel's method

Wang-Mendel's method is a well-known method, which combines both numerical data and expert opinion for the design of fuzzy rules (Wang & Mendel, 1992). Scientists Wang and Mendel designated this method in 1992. The main steps of the Wang-Mendel method are given below.

Step 1. Divide the Input and Output Spaces into Fuzzy Regions

It can be assumed that the domain intervals of x_1, x_2 and y are $[x_1^-, x_1^+]$, $[x_2^-, x_2^+]$ and $[y^-, y^+]$, respectively, where "domain interval" of a variable means that most probably this variable will lie in this interval (the values of a variable are allowed to lie outside its domain interval). Each domain interval needs to be divided into 2N+1 region, denoted by SN (Small N), … , S1 (Small 1), CE (Center), B1 (Big l), …, BN (Big N) and assigned each region a fuzzy membership function. The most often used shape of a membership function is triangular, but some other types there are existing such as trapezoidal, generalized bell-shaped, Gaussian etc. Fig. 8 shows an example where the domain interval of x_1 is divided into five regions (N = 2); the domain region of x_2 is divided into seven regions (N = 3) and the domain interval of y is divided into five regions (N = 2). The shape of each membership function is triangular;

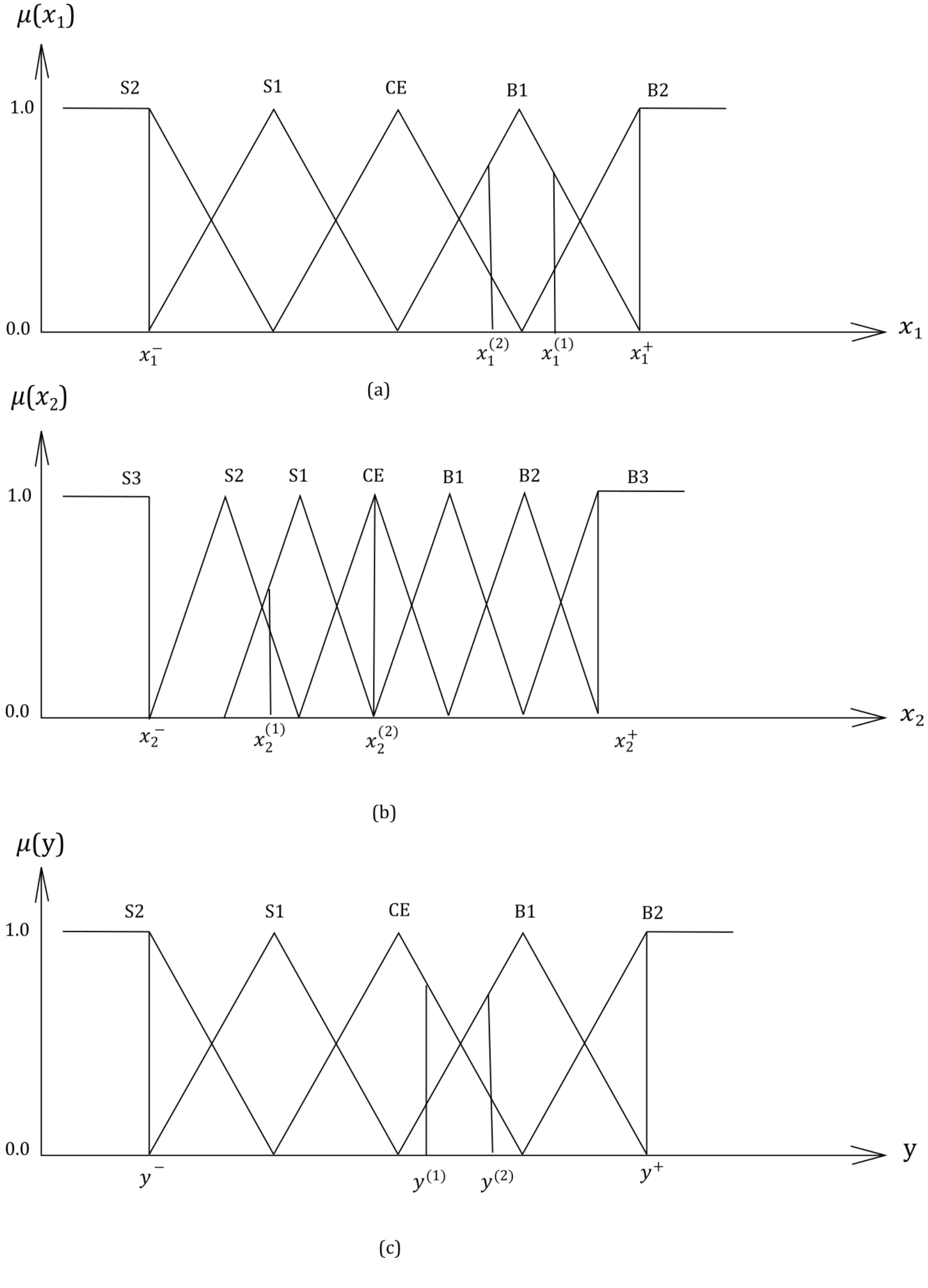

Fig. 8. Divisions of the input and output spaces into fuzzy regions and the corresponding membership functions (μ(x_1); μ(x_2); μ(y)) (adjusted based on Wang & Mendel, 1992)

Step 2. Generate Fuzzy Rules from Given Data Pairs

In order to generate fuzzy rules from given data pairs, first, it is necessary to determine the degrees of given $x_1^{(i)}, x_2^{(i)}$ and $y^{(i)}$ in different regions. For example, $x_1^{(1)}$ in Fig. 8 has degree 0.8 in B1, degree 0.2 in B2 and zero degrees in all other regions. Similarly, $x_2^{(2)}$ in Fig. 8 has degree 1 in CE and zero degrees in all other regions. Second, assign a given $x_1^{(i)}, x_2^{(i)}$ or $y^{(i)}$ to the region with maximum degree. For example, $x_1^{(1)}$ ($\mu(x_1)$) in Fig. 8 is considered B1 and $x_2^{(2)}$ ($\mu(x_2)$) is considered CE. Finally, obtain one rule from one pair of desired input-output data, e.g.,

$(x_1^{(1)}, x_2^{(1)}; y^{(1)}) \Rightarrow [x_1^{(1)}(0.8 \text{ in B1, max}), x_2^{(1)}(0.7 \text{ in S1, max}); y^{(1)}(0.9 \text{ in CE, max})] \Rightarrow$ Rule1

IF x_1 is B1 and x_2 is S1, THEN y is CE;

$(x_1^{(2)}, x_2^{(2)}; y^{(2)}) \Rightarrow [x_1^{(2)}(0.6 \text{ in B1, max}), x_2^{(2)}(1 \text{ in CE, max}); y^{(2)}(0.7 \text{ in B1 max})] \Rightarrow$ Rule2

IF x_1 is B1 and x_2 is CE, THEN y is B1;

Step 3. Assign a Degree to Each Rule

Since there are usually lots of data pairs and each data pair generates one rule, it is highly probable that there will be some conflicting rules, i.e., rules that have the same IF part but a different THEN part. One way to resolve this conflict is to assign a degree to each rule generated from data pairs and accept only the rule from a conflict group that has a maximum degree. In this way, not only is the conflict problem resolved but also the number of the rules is greatly reduced. The following product strategy is used to assign a degree to each rule: for the rule: "IF x_1 is A and x_2 is B, THEN y is C" the degree of this rule, denoted by D(Rule), is defined as: D(Rule) = $\mu_A(x_1)\ \mu_B(x_2)\ \mu$(y). As an example, Rule 1 has degree:

D(Rule 1) = $\mu_{B1}(x_1)\ \mu_{S1}(x_2)\ \mu_{CE}$(y) = 0.8 x 0.7 x 0.9 = 0.504

In practice, we often have some a priori information about the data pairs. For example, if we let an expert check given data pairs, the expert may suggest that some are very useful and crucial, but others are very unlikely and may be caused just by measurement errors.

Step 4. Create a Combined Fuzzy Rule Base

The form of a fuzzy rule base is presented in Fig. 9.

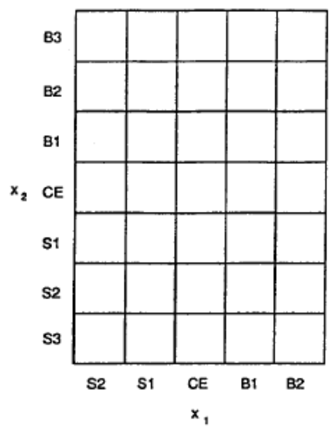

Fig. 9. The form of a fuzzy rule base (Wang & Mendel, 1992)

The boxes of the base are filled with fuzzy rules according to the following strategy: a combined fuzzy rule base is assigned rules from either those generated from numerical data or linguistic rules (we assume that a linguistic rule also has a degree that is assigned by the human expert and reflects the expert's belief of the importance of the rule); if there is more than one rule in one box of the fuzzy rule base, use the rule that has a maximum degree. In this way, both numerical and linguistic information is codified into a common framework-the combined fuzzy rule base. If a linguistic rule is an "and" rule, it fills only one box of the fuzzy rule base;

Step 5. Determine a Mapping Based on the Combined Fuzzy Rule Base

In this step, the following defuzzification strategy to determine the output control y for given inputs x_1, x_2 is given: first, for given inputs x_1, x_2 we combine the antecedents of the *i-th* fuzzy rule using product operation to determine the degree μ_{Oi}^{i} of the output control corresponding to x_1, x_2, i.e.:

$$\mu_{Oi}^{i} = \mu_{I1}^{i}(x_1)\, \mu_{I2}^{i}(x_2) \quad (28)$$

where O_i denotes the output region of rule i and I_j^i denotes the input region of Rule *i* for the *j-th* component, e.g. Rule 1 gives $\mu_{CE}^{1} = \mu_{B1}(x_1)\, \mu_{S1}(x_2)$ then, we use the following centroid defuzzification formula to determine the output:

$$y = \frac{\sum_{i=1}^{K} \mu_{Oi}^{i} \bar{y}^{i}}{\sum_{i=1}^{K} \mu_{Oi}^{i}} \quad (29)$$

where $\bar{y}^i$ denotes the center value of region O_i (the center of a fuzzy region is defined as the point that has the smallest absolute value among all the points at which the membership function for this region has membership value equal to one) and K is the number of fuzzy rules in the combined fuzzy rule base.

4.3 Fuzzy-AHP method

The Analytic Hierarchy Process (AHP) is a multi-criteria analysis method as mentioned above. Yeh et al. (1999) emphasized that multi-criteria analysis has been widely used to deal with decision problems including multiple criteria. The AHP method uses a pair-wise comparison, through which the preference relations of the pairs of single criteria are detected. To determine the relevance of criteria and sub-criteria, Saaty formulated a scale from 1 to 9. The idea of this scale was to evaluate the level of importance of some criteria (sub-criteria) and compare them to one another. This may be seen as a prerequisite for making "good" decisions in a decision-making process. A specific linguistic statement describes each number on Saaty's scale. These statements facilitate the comparison process of pairs.

The existence of linguistic statements is a suitable ground for the implementation of fuzzy logic. The application of fuzzy set theory to multi-criteria analysis models provides an effective method for formulating a decision problem in a fuzzy environment, where the available information is subjective and imprecise (Yeh et al. 1999; Zadeh, 1965; Bellman & Zadeh, 1970). Van Laarhoven and Pedrycz (1983) performed one of the first Fuzzy AHP applications. They defined the triangular membership functions for the pairwise comparison. The following Fuzzy-AHP approach was given in several steps, and it is presented throughout the remainder of the paper as a continuation of the paper.

Step 1: Formulation of Saaty's Fuzzy-AHP scale with linguistic terms. In this step, the criteria and sub-criteria are compared based on the proposed linguistic statements presented in Table 13.

Table 13. Fuzzy AHP Saaty's scale (based on Saaty, 1980)

Classic Saaty's Scale	Linguistic Terms	Fuzzy Scale (Triangular Scale)
1	Equally important	(1,1,1)
3	Weakly important	(2,3,4)
5	Fairly important	(4,5,6)

7	Strongly important	(6,7,8)
9	Absolutely important	(9,9,9)
2	Values designed for evaluation of so-called interphase	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

According to the chosen linguistic term, a decision-maker uses the corresponding fuzzy number. For example, if a decision-maker states, "Criterion 1 is strongly important compared with Criterion 2", then the fuzzy triangular scale is (6, 7, 8). On the contrary, in the pairwise comparison matrix of the criteria, the comparison of Criterion 2 to Criterion 1 will have a fuzzy triangular scale of (1/8, 1/7, 1/6). The pairwise comparison of the criteria presented in the form of a matrix is given in Equation (30):

$$\tilde{P}^k = [\tilde{Z}_{11}^k \; \tilde{Z}_{12}^k \; \dots \; \tilde{Z}_{1n}^k \; \tilde{Z}_{21}^k \; \tilde{Z}_{22}^k \; \dots \; \tilde{Z}_{2n}^k \; \dots \; \dots \; \tilde{Z}_{ij}^k \; \dots \; \tilde{Z}_{n1}^k \; \tilde{Z}_{n2}^k \; \dots \; \tilde{Z}_{nn}^k \;] \tag{30}$$

where $\tilde{Z}_{ij}^k$ indicates the k-th decision maker's preference of the i-th criterion over j-th criterion via fuzzy triangular numbers. Here, the sign " ~ " indicates the triangular number demonstration. For example, $\tilde{Z}_{12}^2$ represents the second decision maker's preference of the first over the second criterion and is equal to $\tilde{Z}_{12}^2$ = (6, 7, 8). If there is more than one decision maker, the preferences of each decision maker ($\tilde{Z}_{ij}^k$) are averaged, and ($\tilde{Z}_{ij}$) is calculated in the following way, given in Equation (31):

$$\tilde{Z}_{ij}=\sum_{k=1}^{k} \frac{\tilde{Z}_{ij}^k}{k}. \tag{31}$$

Step 2: According to the averaged preferences, the pairwise contribution matrix is updated, as shown in Equation (32):

$$\tilde{P}= [\tilde{Z}_{11} \; \tilde{Z}_{12} \; \dots \; \tilde{Z}_{1n} \; \tilde{Z}_{21} \; \tilde{Z}_{22} \; \dots \; \tilde{Z}_{2n} \; \dots \; \dots \; \tilde{Z}_{ij} \; \dots \; \tilde{Z}_{n1} \; \tilde{Z}_{n2} \; \dots \; \tilde{Z}_{nn} \;]. \tag{32}$$

Step 3: In this step, it is necessary to find the geometric mean of the fuzzy comparison values. This is done as shown in Equation (33) (Laptate, 2015):

$$\tilde{t}_i= (\prod_{j=1}^{n} \tilde{Z}_{ij})1/\text{n} \; ; \; i=1,2,\dots n \tag{33}$$

In this equation, $\tilde{t}_i$ still represents triangular values.

Step 4: The main task in this step is to find the fuzzy weights of each criterion. This is shown in Equation (33), which includes the following three sub-steps:

Step 4.1 Find the vector summation of each $\tilde{t}_i$;

Step 4.2 Find the (−1) power of summation vector. Replace the fuzzy triangular number to make it go in an increasing order;

Step 4.3 To find the fuzzy weight of criterion i ($\widetilde{W}_i$), it is necessary to multiply each $\tilde{t}_i$ with this reverse vector:

$$\widetilde{W}_i = \tilde{t}_i(\tilde{t}_1 \oplus \tilde{t}_2 \ldots \tilde{t}_n)-1 = (eW_i, fW_i, gW_i). \tag{34}$$

Step 5: Since $\widetilde{W}_i$ values are still fuzzy triangular numbers, they need to be de-fuzzified, and the method of center of area for is used this purpose. This method is the most widely implemented, such as in the paper by Chou and Chang (2008), via applying Equation (35):

$$M_i = \frac{e\widetilde{W}_i + f\widetilde{W}_i + g\widetilde{W}_i}{3}. \tag{35}$$

Step 6: The obtained M_i values from Equation (35) is a non-fuzzy number; however, it needs to be normalized by following Equation (36):

$$N_i = \frac{Mi}{\sum_{i=1}^{n} Mi}. \tag{36}$$

These six steps are performed to find the normalized weights of both the criteria and the sub-criteria. Then, by multiplying each sub-criterion weight by the related criterion, the score for each sub-criterion is calculated. According to these results, the sub-criterion with the highest score is suggested to the decision-maker.

5 A proposal of a decision-making tool in Third-Party Logistics (3PL) provider selection – Illustrative example

This chapter describes the application of the aforementioned methodology to the case study. To apply the methodology previously described, it is necessary to approach the problem through several phases. Fig. 10 presents a decision-making tool proposed in the doctoral dissertation where the main contribution is given in the last phase.

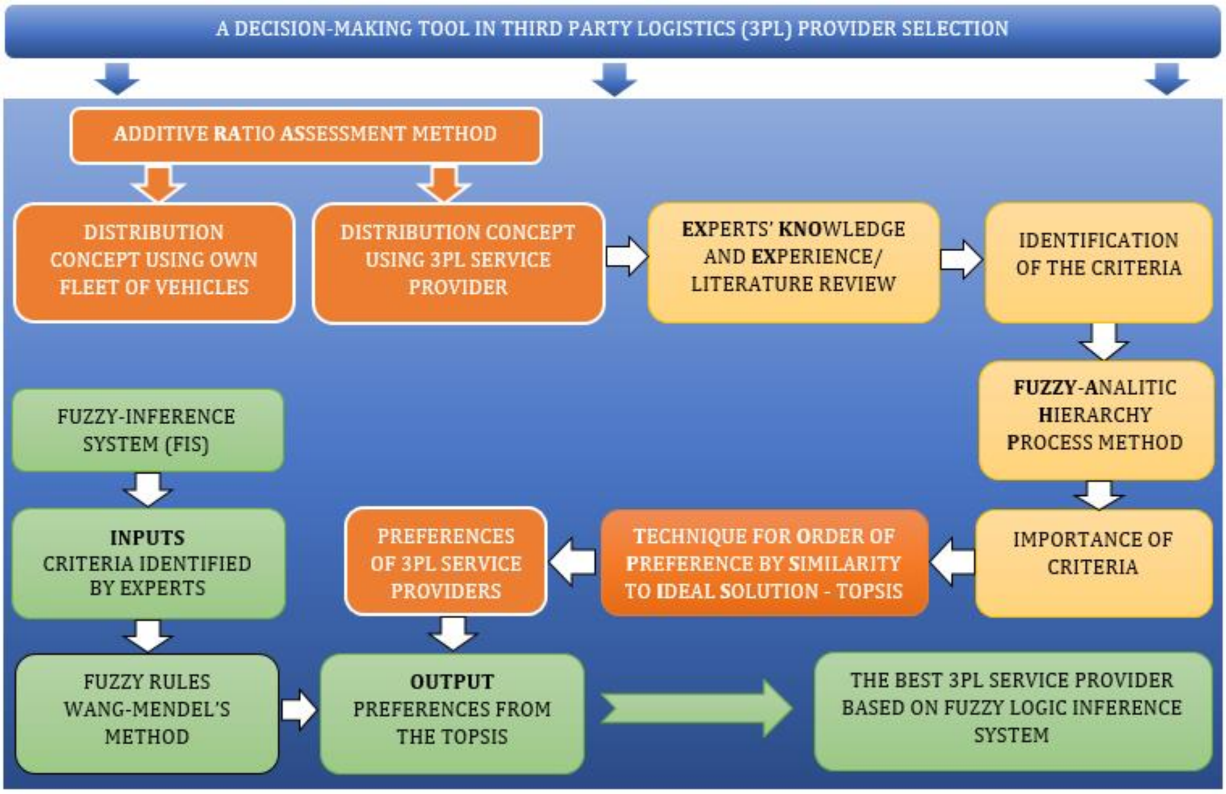

Fig. 10. A decision-making tool for 3PL service provider selection (author)

The first phase of the methodology is to define as well as solve a distribution-concept selection problem. In other words, it is necessary to find out whether the company needs 3PL services for distribution purposes or its fleet of vehicles might organize the distribution. Before the methodology is applied to this kind of problem, the experts' opinions are included to define as well as assess the criteria/sub-criteria. After the criteria are identified and assessed, the Additive Ratio ASsessment (ARAS) method has been applied to find the best distribution concept. Two possible scenarios should be obtained by the ARAS method. The distribution concept by own fleet of vehicles and the distribution concept using the 3PL service providers. When the distribution concept is established, it is necessary to explain the further phase of the methodology proposed. For the case where the second alternative is the best solution, it is of huge importance to know how to evaluate and select the best 3PL service provider for collaboration.

The second-phase starts by identifying the criteria for the 3PL provider evaluation and selection as well as determining its importance. For the criteria identification, an extensive review of the scientific literature, as well as experts' opinions are taken into consideration. To obtain an influential relationship between criteria (criteria weights), the Fuzzy-AHP method is used.

The obtained criteria weights are further used in the third phase where the TOPSIS method is applied. The TOPSIS method is used to rank the 3PL service provider among 25 of them.

The final phase is the main contribution of the doctoral dissertation. Namely, in this phase, a decision-making tool for 3PL provider selection is proposed. This kind of tool uses the criteria identified in the second phase as the inputs, while the results from the TOPSIS are utilized as an output. To obtain the fuzzy rule base, Wang-Mendel's method is applied. The proposed tool is particularly suitable for the implementation when there is no concrete numerical input data about the criteria, but they are given descriptively, through linguistic statements.

5.1 Distribution concept selection problem via ARAS multi-criteria decision-making method

The ARAS method is applied to the distribution concept selection problem based on the idea from a tire manufacturing company in the Czech Republic. The company name is not mentioned according to its legal policy reasons. However, it is one of the major logistics players in the Czech tire manufacturing market. Some of the major benefits of the company reflect through the high level of service, professional staff, and online ordering systems across the Czech Republic. The tire manufacturing company currently has its own fleet of vehicles for the purpose of distribution. However, nowadays, with more increasing customer demands as well as costs, the company considers the possibility to collaborate with third-party logistics partners. According to a discussion with the logisticians working in the company, the author of this dissertation came to the idea to apply a relatively new methodology for distribution concept selection. Two possible alternatives as distribution concepts are considered. The first one (Alternative 1) relates to the distribution concept by its own fleet of vehicles, which has currently been used by the company. On the other side, the second distribution concept (Alternative 2) relates to engaging the 3PL service provider. It is important to emphasize that the logisticians working in the company defined the criteria that would be of the highest interest for the company and society. The hierarchical structure of the distribution concept selection is shown in Fig. 11.

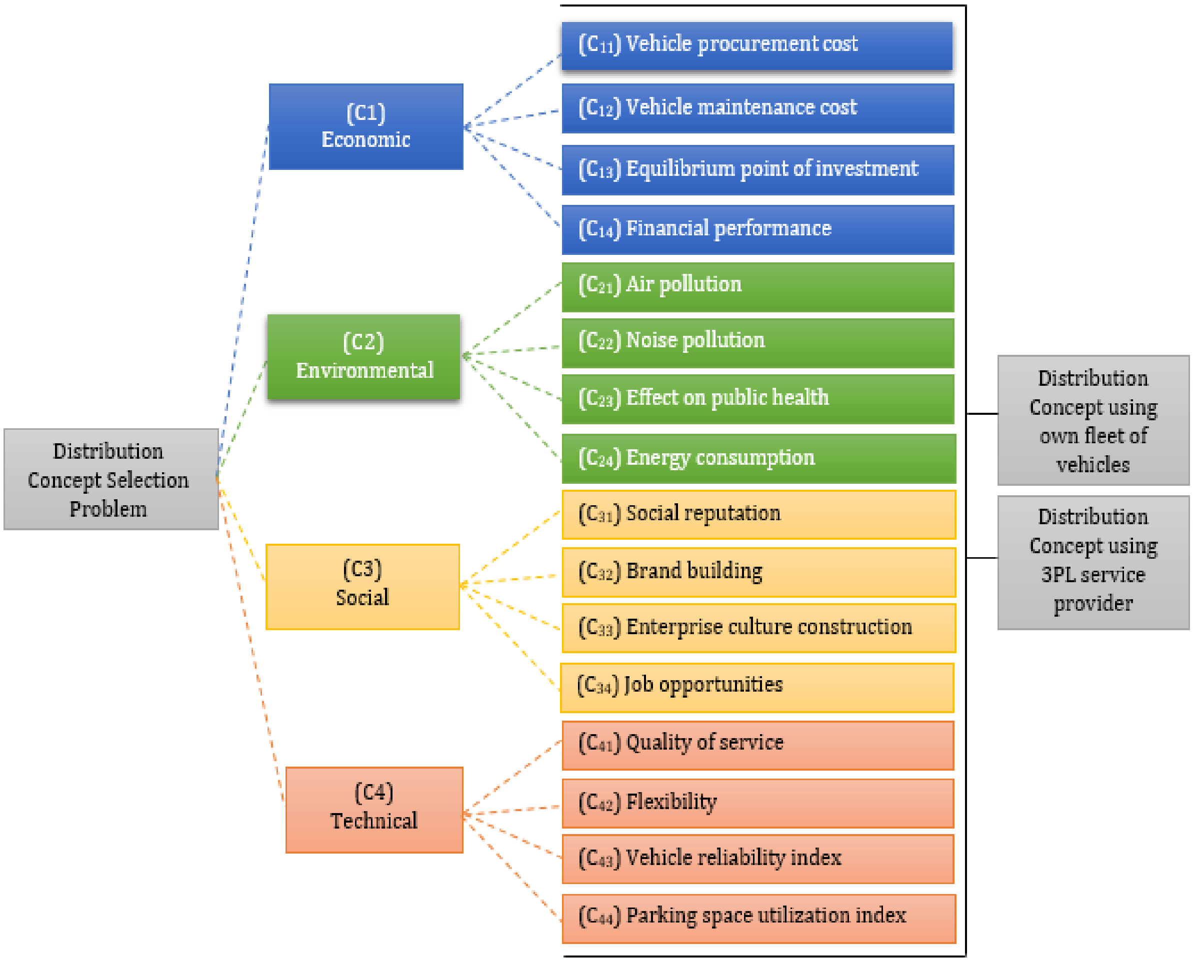

Fig. 11. A hierarchical structure of the distribution-concept selection problem (author)

The economical criterion (C_1) has four sub-criteria:

- (C_{11}) Vehicle procurement cost. It emerges when the company procures its transport fleet. The cost can be considered as a relatively high burden, especially for start-ups.

- (C_{12}) Vehicle maintenance cost. This cost is expressed in terms of parts consumption and maintenance. It is the amount of discounting cash flows spends for servicing during transport fleets' life cycle.

- (C_{13}) Time to achieve the equilibrium point of investment. The period after which the invested funds start to bring benefits to the company.

- (C_{14}) Financial performance. Indication of the company's endurance. Sound financial performance ensures the stability of services.

The environmental criterion (C2) has five sub-criteria:

- (C_{21}) Air pollution. The percentage of air pollution by a certain transport fleet. Emissions could vary in proportion to the alternative, which is selected.

- (C_{22}) Noise pollution. It has a negative impact both on the natural ecosystem and to an urban population. It causes discomfort, complaints, sleep disorders, etc.

- (C_{23}) Effect on public health. The occurrence of injuries, health and life threats, fires, explosions, and other hazards. It is important to apply technical-technological and organizational solutions that minimize the effect on public health.

- (C_{24}) Energy consumption. The pollution from energy consumption is not just limited to carbon emissions; other types of air pollution, from smog to acid rain, have their harmful effects.

The social criterion (C3) has four sub-criteria:

- (C_{31}) Social reputation. It is based on a social appraisal in terms of prestige in society. Adhering to ethical business practices such as supplying quality products on time and acting according to what is agreed secures a high social reputation.

- (C_{32}) Brand building. Successful brand building is essential to introduce new products and services. It can be considered, as is a catalyst for the development of a modern company.

- (C_{33}) Enterprise culture construction. It improves competitiveness by providing a guarantee, feedback, and long-term effect mechanisms.

- (C_{34}) Job opportunities. The number and quality of jobs created.

The technical criterion (C4) has four sub-criteria:

- (C_{41}) Quality of service. The most important factor in obtaining customer loyalty. It is measured by the standard of customer service satisfaction.
- (C_{42}) Flexibility. Ability to react faster on turbulences on the market.
- (C_{43}) Vehicle reliability index. The number of correct vehicles in relation to the total fleet of vehicles.
- (C_{44}) Parking space utilization index. The ratio of the required number of vehicles to the number of available parking spaces.

In order to assess and establish the initial values as well as criteria weights, five logisticians, employed in a cold chain company were included.

The result of their assessment is given in Table 14 and Table 15.

Table 14. Experts' assessment of the first alternative (author)

Alternative 1 - distribution concept by own fleet of vehicles	E_1	E_2	E_3	E_4	E_5	Expert assessment
(C_{11}) Vehicle procurement cost	5	5	3	4	5	4.4
(C_{12}) Vehicle maintenance cost	5	5	5	4	5	4.8
(C_{13}) Time of return on investment	3	3	3	5	3	3.4
(C_{14}) Financial performance	4	4	4	4	4	4
(C_{21}) Air pollution	4	2	5	3	4	3.6
(C_{22}) Noise pollution	4	4	4	3	4	3.8
(C_{23}) Effect on public health	4	4	5	4	4	4.2
(C_{24}) Energy consumption	4	4	4	4	4	4
(C_{31}) Social reputation	4	4	4	5	5	4.4
(C_{32}) Brand building	5	5	5	5	5	5
(C_{33}) Enterprise culture construction	5	5	5	4	4	4.6
(C_{34}) Job opportunities	5	5	2	2	2	3.2
(C_{41}) Quality of service	5	5	5	5	5	5
(C_{42}) Flexibility	4	4	4	5	4	4.2
(C_{43}) Vehicle reliability index	3	3	4	5	4	3.8
(C_{44}) Parking space utilization index	4	4	4	5	4	4.2

Table 15. Experts' assessment of the second alternative (author)

Alternative 2 – distribution concept by 3PL provider	E_1	E_2	E_3	E_4	E_5	Expert assessment
(C_{11}) Vehicle procurement cost	2	2	2	1	1	1.6
(C_{12}) Vehicle maintenance cost	2	2	2	1	1	1.6
(C_{13}) Time of return on investment	2	2	2	3	2	2.2
(C_{14}) Financial performance	3	3	3	4	5	3.6
(C_{21}) Air pollution	4	4	4	3	4	3.8
(C_{22}) Noise pollution	4	4	3	2	3	3.2
(C_{23}) Effect on public health	4	4	4	4	5	4.2

(C_{24}) Energy consumption	4	4	4	3	5	4
(C_{31}) Social reputation	4	4	4	4	5	4.2
(C_{32}) Brand building	4	4	4	5	5	4.4
(C_{33}) Enterprise culture construction	4	4	4	5	5	4.4
(C_{34}) Job opportunities	4	4	3	3	2	3.2
(C_{41}) Quality of service	5	5	5	5	5	5
(C_{42}) Flexibility	4	4	4	5	5	4.4
(C_{43}) Vehicle reliability index	5	5	5	4	4	4.6
(C_{44}) Parking space utilization index	2	2	1	1	1	1.4

After the experts' assessments, the initial decision-making matrix is formulated. It is presented in Table 16.

Table 16. The initial decision-making matrix (author)

Criteria	**Economic**				**Environmental**				**Social**				**Technical**			
Sub-criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
Sub-criteria weights	0.061	0.072	0.052	0.060	0.054	0.057	0.063	0.060	0.067	0.075	0.069	0.048	0.075	0.063	0.057	0.063
Optimal value	1.6	1.6	2.2	3.6	3.6	3.2	4.2	4	4.4	5	4.6	3.2	5	4.4	4.6	4.2
Alternative 1	4.4	4.8	3.4	4	3.6	3.8	4.2	4	4.4	5	4.6	3.2	5	4.2	3.8	4.2
Alternative 2	1.6	1.6	2.2	3.6	3.8	3.2	4.2	4	4.2	4.4	4.4	3.2	5	4.4	4.6	1.4
Sub-criteria type	min	min	min	min	min	min	min	min	max	max	max	max	max	max	max	max

The initial decision-making matrix consists of the sub-criteria, its weights, types as well as two possible alternatives with an additional one – optimal value. It is important to emphasize that the sub-criteria weights are obtained by direct rating. After the first step is completed, the second step according to the ARAS method is the normalization of input data.

By applying the equations (4) and (5), a normalized decision-making matrix is calculated and presented in Table 17.

Table 17. Normalized decision-making matrix (author)

Criteria	**Economic**				**Environmental**				**Social**				**Technical**			
Sub-criteria	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42	C43	C44
Weights	0.061	0.072	0.052	0.06	0.054	0.057	0.063	0.06	0.067	0.075	0.069	0.048	0.075	0.063	0.057	0.063
Opt. Value - 0	0.423	0.429	0.378	0.345	0.334	0.352	0.333	0.046	0.339	0.348	0,339	0.333	0.333	0.339	0.354	0.429
A1	0.154	0.143	0.245	0.310	0.334	0.297	0.333	0.046	0.339	0.348	0.339	0.333	0.333	0.324	0.293	0.429
A2	0.423	0.429	0.378	0.345	0.322	0.352	0.333	0.046	0.324	0.306	0.324	0.333	0.333	0.339	0.354	0.143
Sub-criteria type	min	min	min	min	min	min	min	min	max	max	max	max	max	max	max	max

According to equation (8), the next step is to calculate the weighted decision-making matrix. It is presented in Table 18.

Table 18. Weighted decision-making matrix (author)

Criteria	**Economic**				**Environmental**				**Social**				**Technical**			
Sub-criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
Optimal Value - 0	0.028	0.030	0.019	0.020	0.018	0.020	0.021	0.003	0.022	0.026	0.023	0.016	0.025	0.021	0.020	0.027
Alternative 1	0.010	0.010	0.012	0.018	0.018	0.016	0.021	0.003	0.022	0.026	0.023	0.016	0.025	0.020	0.016	0.027
Alternative 2	0.028	0.030	0.019	0.017	0.017	0.020	0.021	0.003	0.021	0.032	0.022	0.016	0.025	0.021	0.020	0.009

Now it is necessary to determine the value of optimality function (S) as well as the degree of the alternative utility (K) that represents the final rank of the alternatives. It is done by applying the equations (9) and (10) respectively. It is presented in Table 19.

Table 19. Obtained S and K values (author)

Alternatives	**S**	**K**	**RANK**
	0.342		
Alternative 1	0.287	0.839	2.
Aalternative 2	0.318	0.929	1.

From Table 19, it may be seen that a better solution for the distribution concept is assigned to alternative 2. In other words, it is better to make a distribution by engaging the 3PL service provider. To confirm the second alternative as the best one, the topsis method is applied and the results are presented in Table 20.

Table 20. Applied TOPSIS on distribution concept selection (author)

Alternatives	**Preferences obtained by the TOPSIS**
Alternative 1	0.39119
Alternative 2	0.60881

It may be noticed that the TOPSIS method gives the second alternative as a better one. After deciding about the distribution concept, the next phase of the aforementioned methodology is to help decide on 3PL assessment and selection.

5.2 A Fuzzy-AHP approach to estimate the influential relationship between the evaluation criteria for 3PL service provider selection

In this sub-section, before applying the TOPSIS method, the main objective is to identify the criteria and determine the influential relationship between them. The influential relationship between criteria will be solved by the Fuzzy-AHP method. The criteria are defined from an extensive review of the literature combined with the experts' experience. Namely, 15 companies in the Czech Republic, in the field of logistics and supply chain are visited and the author of this dissertation discussed with more than 15 experts. From their point of view, five criteria such as price, delivery, safety, technology level, and social responsibility are chosen to be sorted out (Fig. 12)

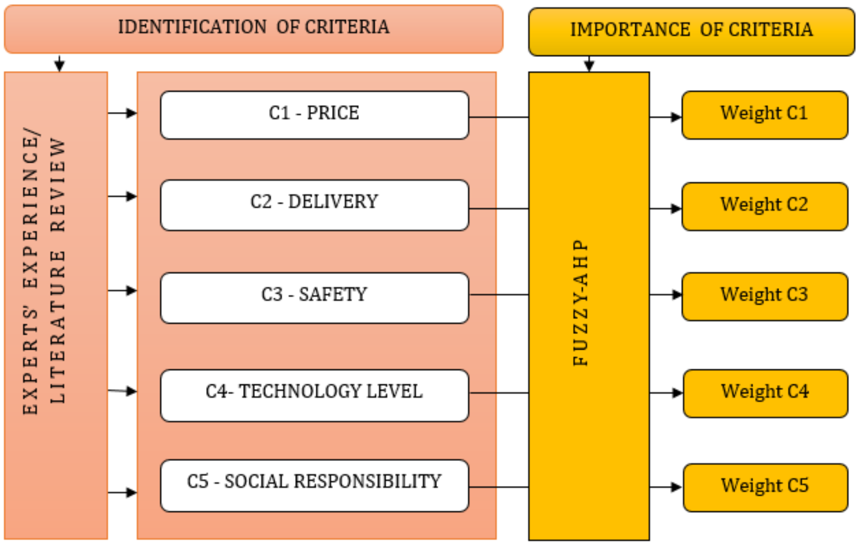

Fig. 12. Identification and assessment of criteria for 3PL selection (author)

When the price is mentioned, it is related to the cost of delivering the service [in eurocent] of a 3PL provider. The delivery criterion relates to the delivery time [in percentage] as well as the condition in which the commodity is delivered. Safety is a criterion that is generally expected to be very important for the customers who are making decisions at the market. The next criterion to which it is also useful to pay attention to the selection of 3PL service providers is the technological level. This implies to what extent a particular logistics provider follows the technological trends, which is of great importance due to high customer expectations. As the last criterion, which is of great importance not only in logistics but also in all spheres of business, is social responsibility.

To determine the criteria weights, it is necessary to formulate the comparison matrix. According to the Fuzzy-Saaty's scale, the evaluation is performed. The comparison matrix is given in Table 21.

Table 21. Comparison matrix for criteria – fuzzy assessments (author)

Criterion	**Price**	**Delivery**	**Safety**	**Technology Level**	**Social Responsibility**
Price	(1,1,1)	(4,5,6)	(3,4,5)	(6,7,8)	(9,9,9)
Delivery	(1/6,1/5,1/4)	(1,1,1)	(1,2,3)	(4,5,6)	(6,7,8)
Safety	(1/5,1/4,1/3)	(1/3,1/2,1/1)	(1,1,1)	(6,7,8)	(9,9,9)
Technology level	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1,1,1)	(1,2,3)
Social Responsibility	(1/9,1/9,1/9)	(1/8,1/7,1/6)	(1/9,1/9,1/9)	(1/3,1/2,1/1)	(1,1,1)

After completing this part, the next step is the geometric mean of fuzzy comparison values of each criterion. It is calculated in the following way:

$\tilde{t}_i = (\prod_{j=1}^{n} \tilde{Z}_{ij})^{1/n}$

Table 22 shows the geometric means of fuzzy comparison values of all criteria, the relative fuzzy weights, the total and reverse values as well as normalized relative weights. Finally, the level of consistency is examined. The result shows that CR = 0.09986 which is less than 0.1. This means the level of consistency is satisfactory.

Table 22. The geometric means of fuzzy comparison values with the total and reverse values and normalized relative weights of criteria (author)

Criterion	The geometric means of fuzzy comparison values	The relative fuzzy weights $\widetilde{W}_i$	Normalized relative weights of criteria
Price	(3.65, 4.17, 4.64)	(0.3913, 0.52, 0.6848)	0.5148
Delivery	(1.31, 1.70, 2.05)	(0.1404, 0.2119, 0.3026)	0.2111
Safety	(1.29, 1.52, 1.88)	(0.1382, 0.1895, 0.2774)	0.1951
Technology level	(0.3041, 0.3822, 0.4609)	(0.0325, 0.0476, 0.0680)	0.0470
Social responsibility	(0.2185, 0.2439, 0.2889)	(0.0234, 0.0304, 0.0426)	0.0310
Total	(6.7726, 8.0161, 9.3198) = (e, f, g)		
Reverse (power -1)	(0.1072, 0.1247, 0.1476)		

The criteria weights are obtained and it may be seen in the table above. The biggest importance of 0.5148 is assigned to the price. After that, the criterion of delivery is in the second place by the importance 0.2111, safety participates with 0.1951, while, technology level and social responsibility are determined as lesser important with 0.047 and 0.031 respectively.

5.3 Application of the TOPSIS methodology for the selection of a 3PL service provider

The TOPSIS methodology is a very reliable tool in determining the preferences of 3PL service providers. In this dissertation, this method is used to select an appropriate 3PL service provider. Twenty-five 3PL service providers are compared and evaluated. The best possible solution is the best preference for 3PL, according to price, delivery, safety, level of technology, and social responsibility. By comparing the 3PL service provider, as a unit for the price, the euro cent per Km has taken. Different logistics providers perform transport services at different prices ranging from 91 to 98 eurocents. When it comes to delivery, the percentage of on-time deliveries is taken. This percentage varies between 88.85 % and 99.98 %. The remaining three criteria concerning safety, level of technology, and social responsibility for 3PL providers are taken into consideration based on a scale from 5 to 10, where 10 indicates the maximum grade.

Since no complete data were available to create a real-life case study, given the time constraints of this research, some hypothetical data have been used within this dissertation. The data for 3PL providers are usually as a rule privately owned. Moreover, some data are not freely available to the general public or the scientific community, probably due to a corporate policy to protect proprietary information. However, the input data for twenty-five 3PL service providers are formulated based on interviews with experts from the Czech Republic and Poland. The experts interviewed belong to the logistics field. The interviewed practitioners confirmed that the illustrative example, generated by the author of the dissertation, was close to the real conditions on the market. Therefore, the purpose of research was to show the applicability of the proposed methodology, especially when a larger sample is considered. Since this is an academic study, the stress is placed on the methodological issue. However, the TOPSIS as well as the methodology based on Fuzzy Inference System (FIS) is general and can be applied in reality to any other logistics company that considers the possibility of employing 3PL providers. Future research will surely address this topic to overcome this limitation and apply the proposed methodology to the real-life study.

The empirical data on 3PL service providers are shown in Table 23.

Table 23. Empirical data for selecting a 3PL provider (author)

	Price	Delivery	Safety	Technology L.	Social Resp.
3PL-1	0.95	99.98	8	10	9
3PL-2	0.96	89.88	8	9	10
3PL-3	0.94	99.54	9	9	10
3PL-4	0.95	99.34	10	9	9
3PL-5	0.93	99.84	10	9	8
3PL-6	0.97	99.62	8	8	9
3PL-7	0.91	98.93	10	8	10
3PL-8	0.95	98.96	10	9	8
3PL-9	0.98	99.74	6	10	8
3PL-10	0.97	99.23	9	9	9
3PL-11	0.91	99.12	8	10	10
3PL-12	0.92	98.96	7	8	8
3PL-13	0.96	88.85	9	7	9
3PL-14	0.95	97.96	10	6	10
3PL-15	0.92	99.66	9	10	10
3PL-16	0.97	98.56	9	8	10

3PL-17	0.94	89.91	9	9	9
3PL-18	0.94	99.95	8	8	8
3PL-19	0.98	97.54	10	8	9
3PL-20	0.96	98.33	9	7	10
3PL-21	0.97	99.44	10	7	8
3PL-22	0.93	97.33	9	8	8
3PL-23	0.90	99.94	10	8	10
3PL-24	0.98	98.89	8	10	9
3PL-25	0.96	97.95	10	10	7

The next step, followed by the methodology, is the normalization of input data. It is performed by finding the sum by the columns of all the criteria separately and then dividing each element by the sum in the given column. The results of the previously implemented Fuzzy-AHP method, where the importance of criteria is determined, are used in the TOPSIS method. Each value obtained by normalization is multiplied with a given weight. Table 24 shows the weighted decision-making matrix. The result obtained by the TOPSIS is represented in Table 25 and Figure 13.

Table 24. Weighted decision-making matrix (author)

	Price	**Delivery**	**Safety**	**Technology level**	**Social Responsibility**
3PL-1	0.1031	0.0431	0.0348	0.0111	0.0062
3PL-2	0.1042	0.0387	0.0348	0.0100	0.0069
3PL-3	0.1021	0.0429	0.0391	0.0100	0.0069
3PL-4	0.1031	0.0428	0.0434	0.0100	0.0062
3PL-5	0.1010	0.0430	0.0434	0.0100	0.0055
3PL-6	0.1053	0.0429	0.0348	0.0089	0.0062
3PL-7	0.0988	0.0426	0.0434	0.0089	0.0069
3PL-8	0.1031	0.0427	0.0434	0.0100	0.0055
3PL-9	0.1064	0.0430	0.0261	0.0111	0.0055
3PL-10	0.1053	0.0428	0.0391	0.0100	0.0062
3PL-11	0.0988	0.0427	0.0348	0.0111	0.0069
3PL-12	0.0999	0.0427	0.0304	0.0089	0.0055
3PL-13	0.1042	0.0383	0.0391	0.0078	0.0062
3PL-14	0.1031	0.0422	0.0434	0.0067	0.0069
3PL-15	0.0999	0.0430	0.0391	0.0111	0.0069
3PL-16	0.1053	0.0425	0.0391	0.0089	0.0069
3PL-17	0.1021	0.0388	0.0391	0.0100	0.0062
3PL-18	0.1021	0.0431	0.0348	0.0089	0.0055
3PL-19	0.1064	0.0420	0.0434	0.0089	0.0062
3PL-20	0.1042	0.0424	0.0391	0.0078	0.0069
3PL-21	0.1053	0.0429	0.0434	0.0078	0.0055
3PL-22	0.1010	0.0420	0.0391	0.0089	0.0055
3PL-23	0.0977	0.0431	0.0434	0.0089	0.0069
3PL-24	0.1064	0.0426	0.0348	0.0111	0.0062
3PL-25	0.1042	0.0422	0.0434	0.0111	0.0048

A+	0.0977	0.0431	0.0434	0.0111	0.0069
A-	0.1064	0.0383	0.0261	0.0067	0.0048
	MIN	MAX	MAX	MAX	MAX

Table 25. The distance from an ideal and anti-ideal solution and closeness to the ideal solution (author)

Si+		Si-		Ci
S1+	0.0103	S1-	0.0114	0.5268
S2+	0.0118	S2-	0.0098	0.4543
S3+	0.0062	S3-	0.0150	0.7061
S4+	0.0056	S4+	0.0186	0.7689
S5+	0.0037	S5+	0.0191	0.8375
S6+	0.0118	S6+	0.0102	0.4653
S7+	0.0025	S7+	0.0197	0.8868
S8+	0.0057	S8+	0.0185	0.7638
S9+	0.0195	S9+	0.0065	0.2501
S10+	0.0089	S10+	0.0143	0.6172
S11+	0.0088	S11+	0.0133	0.6027
S12+	0.0135	S12+	0.0093	0.4072
S13+	0.0098	S13+	0.0133	0.5764
S14+	0.0071	S14+	0.0182	0.7206
S15+	0.0049	S15+	0.0161	0.7677
S16+	0.0091	S16+	0.0141	0.6083
S17+	0.0076	S17+	0.0142	0.6505
S18+	0.0101	S18+	0.0111	0.5240
S19+	0.0091	S19+	0.0180	0.6649
S20+	0.0085	S20+	0.0140	0.6216
S21+	0.0084	S21+	0.0180	0.6820
S22+	0.0061	S22+	0.0148	0.7065
S23+	0.0022	S23+	0.0202	0.9011
S24+	0.0123	S24+	0.0108	0.4663
S25+	0.0069	S25+	0.0185	0.7285

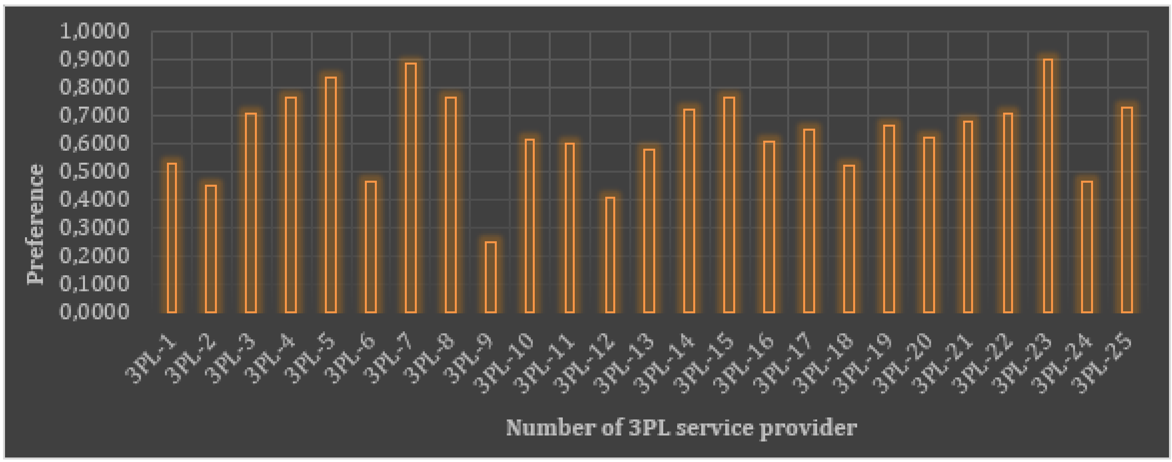

Fig. 13. Final rank of 3PL providers (author)

5.3.1 Sensitivity analysis of TOPSIS methodology

Since the weights of the criteria are determined according to the expert opinion, it is useful to perform a sensitivity analysis of the implemented TOPSIS methodology. This means that it is examined how the change in the weight of one criterion affects the final ranking of alternatives. However, since the sum of all criteria is equal to 1, if the weight of the p-th criteria changes by Δp, then the weight of other criteria changes by Δj, where (Alinezhad and Anini, 2011):

$$\Delta_j = \frac{\Delta_p \cdot w_j}{w_p - 1} \tag{37}$$

The result of testing the criteria Price are given in Table 26. In the first column, there is a level of the weight change for the first criterion Price, then in the second column, there are new values of weights for all five criteria, and finally, the best-ranked 3PL service provider is presented. In Table 27, there are the results about testing the remaining criteria: Delivery, Safety, Technology Level, and Social Responsibility.

Table 26. The effect of weights changing for the criterion Price (author)

$\boldsymbol{\Delta_1}$	$\boldsymbol{w_i, i = 1,5}$	**The best-ranked 3PL**
-0.34	0.1748 0.3590 0.3318 0.0815 0.0529	3PL-4
-0.33	0.1848 0.3547 0.3278 0.0805 0.0523	3PL-4
-0.32	0.1948 0.3503 0.3238 0.0795 0.0516	3PL-4
-0.31	0.2048 0.3460 0.3198 0.0785 0.0510	3PL-4
-0.30	0.2148 0.3416 0.3157 0.0775	3PL-4

	0.0503	
-0.20	0.3148	3PL-23
	0.2981	
	0.2755	
	0.0676	
	0.0439	
-0.10	0.4148	3PL-23
	0.2546	
	0.2353	
	0.0578	
	0.0375	
0.10	0.6148	3PL-23
	0.1676	
	0.1549	
	0.0380	
	0.0247	
0.20	0.7148	3PL-23
	0.1241	
	0.1147	
	0.0282	
	0.0183	
0.30	0.8148	3PL-23
	0.0806	
	0.0745	
	0.0183	
	0.0119	
0.40	0.9148	3PL-23
	0.0371	
	0.0343	
	0.0084	
	0.0055	

The results of sensitivity analysis reveal that the most stable criteria in the proposed model are Price, Delivery and Technology level. On the other hand, relatively smaller changes in weights for Safety and Social responsibility lead to a change in ranking of alternatives.

Table 27. The effect of weights changing for the criteria Delivery, Safety, Technology level and Social responsibility (author)

Δ_2	**The best – ranked 3PL**	Δ_3	**The best – ranked 3PL**	Δ_4	**The best – ranked 3PL**	Δ_5	**The best – ranked 3PL**
-0.2	3PL-23	-0.14	3PL-23	-0.035	3PL-23	-0.03	3PL-23
-0.1	3PL-23	-0.15	3PL-11	-0.03	3PL-23	-0.02	3PL-23
0.1	3PL-23	0.1	3PL-23	0.03	3PL-23	-0.01	3PL-23
0.2	3PL-23	0.3	3PL-23	0.04	3PL-23	0.5	3PL-23

0.3	3PL-23	0.5	3PL-23	0.05	3PL-5	0.96	3PL-23

5.4 The proposal of fuzzy model for 3PL provider selection based on empirical data

In this sub-section, the main contribution of this dissertation may be found. A fuzzy inference system (FIS) is developed for selecting a third-party logistics provider (Fig. 14).

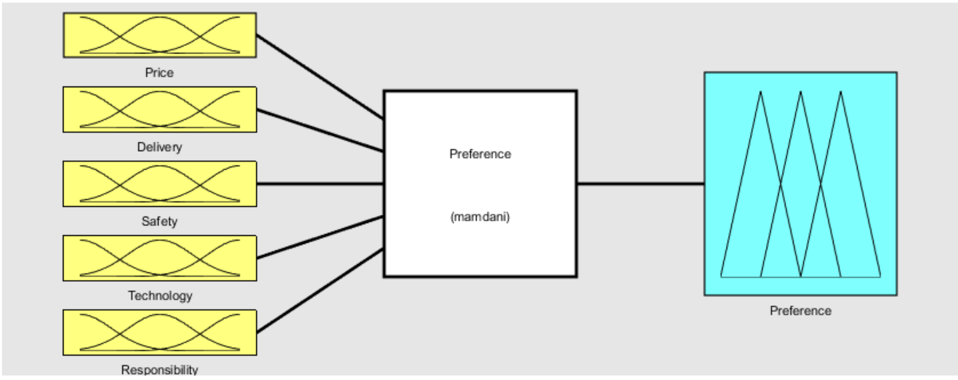

Fig. 14. The proposal of fuzzy model for 3PL selection (author)

The proposed FIS is designed by using the empirical data, which are obtained in the previous part of this dissertation. The considered criteria, price, delivery, safety, technology level, and social responsibility are taken as input variables. The output variable is a preference for the 3PL provider. The FIS is based on Wang-Mendel 's method for determining fuzzy rules. The fuzzy rules are essential for the design of FIS and by that for forming a decision-making tool for 3PL selection. There is a possibility to implement the interval type-2 fuzzy sets for the same purpose (Senturk et al. 2017, Ghorabaee et al. 2017); however, in this case, the type 1 fuzzy system achieved satisfactory results.

5.4.1 Input and output variables

The first input variable is the price and it is described by three fuzzy sets: Low price (LP), Medium price (MP), and High price (HP). As for the price, the upper and lower limits are set for all other criteria as well as the average values. This is done by analyzing the empirical data collected by the author of this dissertation. It is supposed, according to empirical data that the price is low if the 3PL service provider provides transport service between 83.32 and 94.8 Euro-Cent per km. The price is medium (MP) if the 3PL service provider requests the costs for transport service between 91 and 98 Euro-Cent per km. The price is high (HP) if the transport costs are between 94.8 and 106 Euro-Cent per km.

Similarly, all the other variables are defined based on the collected data. The descriptive statistics of the sample are shown in Table 28. Consequently, the input-output variables are designed as shown in Fig. 15 to Fig. 20.

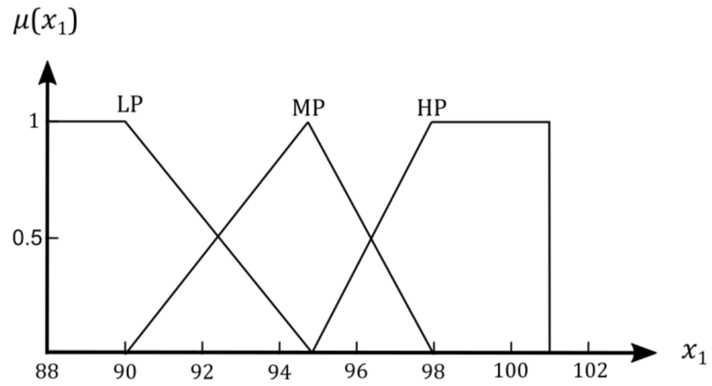

Fig. 15. The first input variable – "Price" described by membership functions (author)

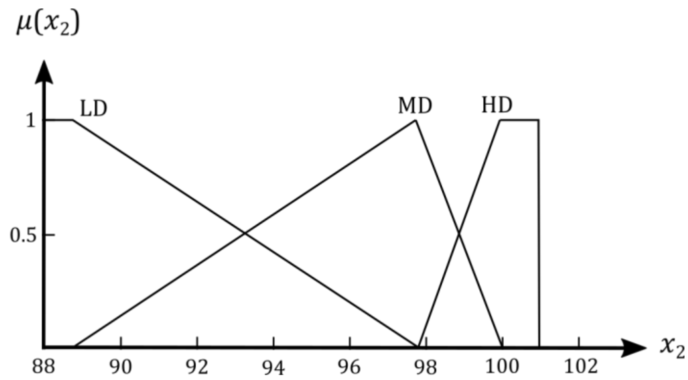

Fig. 16. The second input variable – "Delivery" described by membership functions (author)

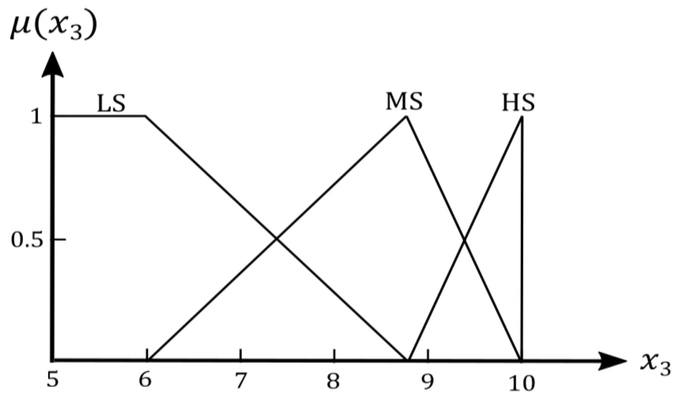

Fig. 17 The third input variable – "Safety" described by membership functions (author)

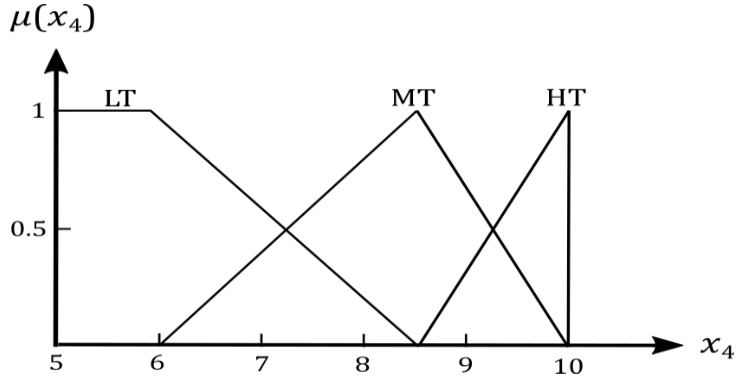

Fig. 18. The fourth input variable – "Technology level" described by membership functions (author)

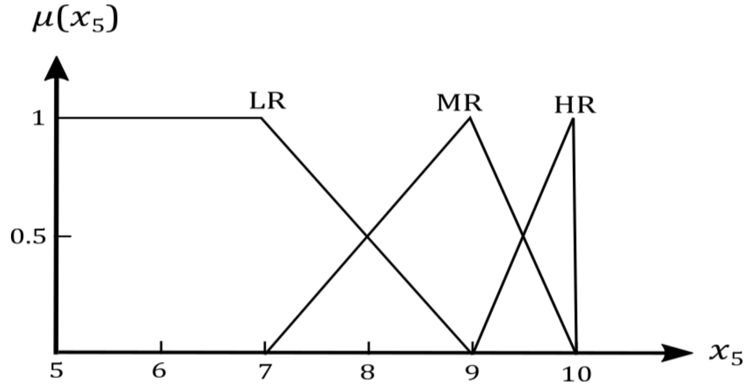

Fig. 19. The fifth input variable – "Social responsibility" described by membership functions (author)

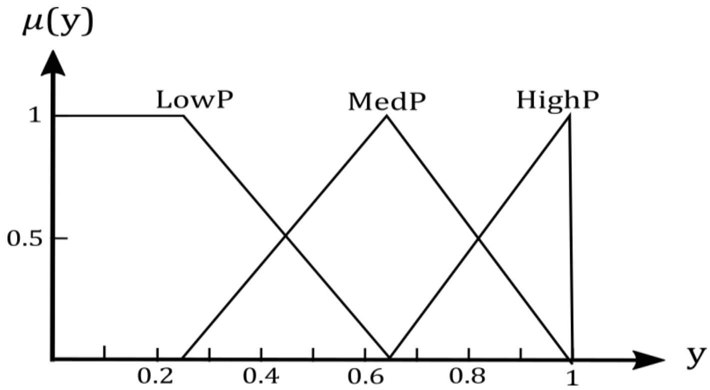

Fig. 20. The output variable – "Preference" described by membership functions (author)

Table 28. Descriptive statistics of the sampe (author)

Input Variable	Domain	Sample		
		min	max	average
x_1- Price	[88-101]	90	98	94.80
x_2-Delivery	[88-101]	88.85	99.98	97.90
x_3-Safety	[5-10]	6	10	8.92
x_4-Technology level	[5-10]	6	10	8.56
x_5-Social Responsibility	[5-10]	7	10	9
y-Output variable The preference for 3PL	[0-1]	0.25	0.90	0.64

5.4.2 Determining the fuzzy rules

In the continuation of the dissertation, the author used a well-known method, which combines both numerical data and expert opinion for the design of fuzzy rules. Wang-Mendel‘s method, characterized by 5 steps (Wang and Mendel, 1992), is implemented:

The first step divides the input and output spaces into fuzzy regions. The second step generates fuzzy rules from the given data pairs. The third step assigns a degree to each rule. Since there are usually lots of data pairs and each data pair generates one rule there will probably be some rules, so-called conflicting rules that have the same „if“ part, but a different „then“ part. Based on the calculated degree of each rule, which is obtained by implementing the appropriate programming code, the non-conflict fuzzy rules that form the final rule database is selected. The fourth step creates a combined fuzzy rule database, on both the linguistic rules of a human expert and the generated rules from data. Finally, the last step determines a mapping based on the combined fuzzy rule base using a de-fuzzifying procedure.

A set of input-output data pairs is formulated:

$x_1{}^{(1)}\ x_2{}^{(1)}\ x_3{}^{(1)}\ x_4{}^{(1)}\ x_5{}^{(1)}\ y^{(1)}$

$x_1{}^{(2)}\ x_2{}^{(2)}\ x_3{}^{(2)}\ x_4{}^{(2)}\ x_5{}^{(2)}\ y^{(2)}$

… … … … …

$x_1{}^{(25)}\ x_2{}^{(25)}\ x_3{}^{(25)}\ x_4{}^{(25)}\ x_5{}^{(25)}\ y^{(25)}$ (38)

x_1, x_2, x_3, x_4, and x_5 (x_1– price, x_2 – delivery, x_3 – safety, x_4 – a level of technology, x_5 – social responsibility) are taken as inputs in the FIS. Y represents an output of the system (a preference for 3PL service provider). The numbers in brackets represent the exact 3PL provider. This is a five-input, one-output case. The task is to generate a set of fuzzy rules from the collected input-output data pairs and use these fuzzy rules to determine a mapping $(x_1, x_2, x_3, x_4, x_5)$ -> y

Step 1. Divide the input and output spaces into fuzzy regions

According to the empirical data the domain intervals of x_1, x_2, x_3, x_4, x_5 and y are set up as: $[x_1^- - x_1^+]$, $[x_2^- - x_2^+]$, $[x_3^- - x_3^+]$, $[x_4^- - x_4^+]$, $[x_5^- - x_5^+]$, $[y^- - y^+]$, where “domain interval” of variable means that most probably the values of this variable will be in the set interval.

Each domain interval should be divided into 2N+1 regions. In this case, each variable is defined by three regions: L (Low), M (Medium), and H (High).

A fuzzy membership function is assigned to each region, which is done based on data shown in Table 28.

Fig. 15 – Fig. 20 present the domain intervals from x_1 to x_5 respectively, divided into three regions (fuzzy sets) and the domain interval of an output variable y is divided into three regions as well. The shape of each membership function is triangular. Even though the shapes of membership functions may be different, it is not expected that this should change the results significantly.

Step 2. Generate Fuzzy Rules from Given Data Pairs

In this step, the degrees of given x_1(i), x_2(i), x_3(i), x_4(i), x_5(i) and y(i) in different regions are determined, and the regions with the maximum degree are selected. For example, in the case of 10th 3PL provider, x_1(10)=97 cents. This value has a degree equal to 0.3125 in MP and degree 0.6875 in HP. The remaining region is not considered since its degree is equal to zero. The value of membership degrees for all variables in the case of the 10th 3PL provider has presented in Table 29.

Table 29. The membership degrees of regions for 3PL number 10 (author)

	Degree for $x_1^{(10)}$=97	Degree for $x_2^{(10)}$=99.23	Degree for $x_3^{(10)}$=9	Degree for $x_4^{(10)}$=9	Degree for $x_5^{(10)}$=9	Degree for $y^{(10)}$= 0.7692
Low	0	0	0	0	0.1304	0
Medium	0.3125	0.3275	0.8333	0.6897	0.8696	0.4817
High	0.6875	0.6725	0.1667	0.3103	0	0.5183

Based on the obtained values of degrees where the maximum degrees are bolded, the following fuzzy rule may be formed:

IF $\boldsymbol{x_1}$ is ***High Price (HP)*** and $\boldsymbol{x_2}$ is ***High Delivery (HD)*** and $\boldsymbol{x_3}$ is ***Medium Safety (MD)*** and $\boldsymbol{x_4}$ is ***Medium Technology (MT)*** and $\boldsymbol{x_5}$ is ***Medium Responsibility (MR)***, THEN ***y*** is ***High Preference (HighP)***.

This procedure is performed for all remaining 3PL providers from the sample; therefore, the 19 fuzzy rules are obtained.

Step 3. Elimination of the same or conflict rules

The purpose of this step is to form a fuzzy rule base containing just rules from empirical data that are not conflicting or the same. The conflict rules have the same IF part, but a different THEN part. To resolve this, the degree of each rule – D(i) should be calculated, for the case when a rule is defined as follows: "IF x_1 is A and x_2 is B and x_3 is C and x_4 is D and x_5 is E THEN y is F".

$$D(i) = \mu_A(x_1) \cdot \mu_B(x_2) \cdot \mu_C(x_3) \cdot \mu_D(x_4) \cdot \mu_E(x_5) \cdot \mu_F(y) \tag{39}$$

$D(i)$ is a degree of i-th rule $\mu_A(x_1)$, is a value of membership function of the region A when the input value is x_1, etc. In a conflict group, only the rule that has a maximum degree may be accepted. In this case, the 19 rules from empirical data in the final fuzzy rule base are obtained, which is shown in Table 30.

Step 4. Design of combined fuzzy rule base

The final fuzzy rule base should consist of 243 fuzzy rules. Besides previously mentioned 19 rules that are obtained based on empirical data, the remaining rules are generated based on expert opinion. In this process, the following logic is implemented: if the price of service is higher, then the preference for selection of an observed 3PL provider is lower; if delivery is higher, then the preference is higher; if safety is higher, then the preference is higher; if a technology level is higher, then the preference is higher and if social responsibility is higher, then the preference is higher.

Table 30. The Fuzzy-rules based on Wang-Mendel (author)

D(i)	Serial number of $\mu_A(x_1)$	Serial number of $\mu_B(x_2)$	Serial number of $\mu_C(x_3)$	Serial number of $\mu_D(x_4)$	Serial number of $\mu_E(x_5)$	Serial number of $\mu_F(y)$
0.1414	1.0000	2.0000	3.0000	2.0000	2.0000	3.0000
0.0467	1.0000	3.0000	1.0000	2.0000	2.0000	1.0000
0.2876	1.0000	3.0000	2.0000	3.0000	3.0000	2.0000
0.6477	1.0000	3.0000	3.0000	2.0000	2.0000	3.0000
0.2982	2.0000	1.0000	2.0000	1.0000	1.0000	2.0000
0.4308	2.0000	1.0000	2.0000	2.0000	2.0000	2.0000
0.2693	2.0000	2.0000	2.0000	1.0000	1.0000	2.0000
0.1570	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000
0.6032	2.0000	2.0000	3.0000	1.0000	1.0000	2.0000
0.3856	2.0000	2.0000	3.0000	3.0000	3.0000	2.0000
0.2914	2.0000	3.0000	2.0000	2.0000	2.0000	2.0000
0.4556	2.0000	3.0000	2.0000	3.0000	3.0000	2.0000

0.2719	2.0000	3.0000	3.0000	2.0000	2.0000	3.0000
0.1600	3.0000	2.0000	2.0000	2.0000	2.0000	2.0000
0.1990	3.0000	2.0000	2.0000	3.0000	3.0000	2.0000
0.3446	3.0000	2.0000	3.0000	2.0000	2.0000	2.0000
0.8846	3.0000	3.0000	1.0000	3.0000	3.0000	1.0000
0.2535	3.0000	3.0000	2.0000	2.0000	2.0000	2.0000
0.2583	3.0000	3.0000	3.0000	1.0000	1.0000	2.0000

Step 5. Determine a mapping based on the combined fuzzy rule base

In this step, the proposed FIS is tested and the obtained results are given in Table 31.

To compare the results of FIS and preferences obtained by the TOPSIS the Cumulative Error (CE) is calculated according to equation (40) (Čubranić-Dobrodolac et al. (2019)).

$$CE = \sum_{i=1}^{25} \left| y^{(i)} - Preference(i) \right| \quad (40)$$

where: CE represents a Cumulative Error in description of data, $y^{(i)}$ is the preference, calculated by the TOPSIS and $Preference(i)$ is the result of FIS.

The value CE may be used to compare the proposed FIS and some other which would be defined based on some other principles. The smaller value of CE indicates a better matching between the empirical data and FIS. A comparison of the results from this research obtained by TOPSIS and FIS is shown in Fig. 21. By analyzing Fig. 21, it is possible to conclude that the proposed FIS gives similar results to TOPSIS, but at the same time, the best solution is obtained according to both of the methods; however, there is a possibility for the improvement of this FIS structure. The statement is based on the fact that, in this empirical case, the best ranking 3PL service provider is not totally the same in two proposed decision-making techniques.

The explanation for this discrepancy may be found in Table 31, where the highest deviation is 0.3643. An optimization of FIS structure can be done in various ways and in this dissertation; the effects of change in shapes of membership functions are tested.

Table 31. Testing of FIS (author)

The result obtained by the TOPSIS method	The result obtained by the fuzzy system with 243 rules	Cumulative Error – CE
0.5268	0.5862	0.0594
0.4543	0.6380	0.1837
0.7061	0.6207	0.0854
0.7689	0.7232	0.0456
0.8375	0.4867	0.3508

0.4653	0.5037	0.0385
0.8868	0.7214	0.1654
0.7638	0.4991	0.2647
0.2501	0.4082	0.1580
0.6172	0.5975	0.0197
0.6027	0.6208	0.0181
0.4072	0.4082	0.0010
0.5764	0.4510	0.1254
0.7206	0.5939	0.1267
0.7677	0.6112	0.1566
0.6083	0.7209	0.1126
0.6505	0.5982	0.0523
0.5240	0.4550	0.0689
0.6649	0.5880	0.0769
0.6216	0.6488	0.0272
0.6820	0.5173	0.1647
0.7065	0.4206	0.2859
0.9011	0.7557	0.1453
0.4663	0.5823	0.1159
0.7285	0.3642	0.3643
		$\sum$ = 3.2130

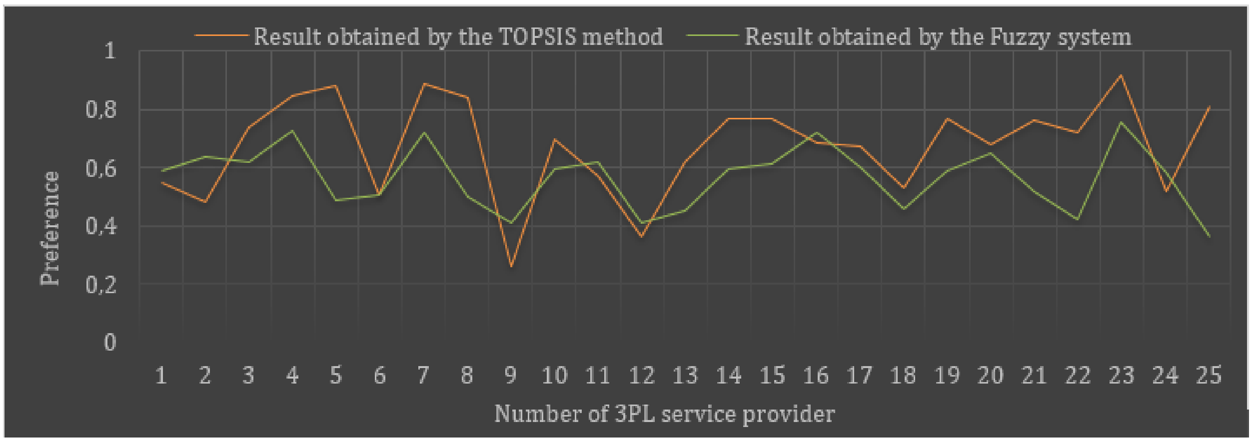

Fig. 21. Comparison of the results obtained by TOPSIS and FIS

5.4.3 Sensitivity analysis of the proposed fuzzy model based on change in shapes of membership functions

In the case of triangular membership functions, the value of CE is equal to 3.2130. This value of CE is further compared with other FIS structures where the shapes of membership functions are changed. Additionally, the testing of different FIS structures may be seen as a starting point in the optimization of FIS structure in pursuance of achieving the same conclusion about the best 3PL provider as in the case of TOPSIS. The results of testing may be found in Table 32.

Table 32. Stability testing of FIS structures and comparing of CE values (author)

Shape of membership function	CE	Serial number of chosen 3PL service provider
Triangular – trimf	3.2130	3PL-23
Trapezoidal – trapmf	3.2242	3PL-23
Generalized bell-shaped – gbellmf	3.0784	3PL-7
Gaussian – gaussmf	3.5385	3PL-23
Gaussian combination – gauss2mf	3.1442	3PL-23
zmf, pimf, smf	3.0855	3PL-23

The conclusion of the testing procedure related to changing the shape of membership functions is that there are no differences in the best 3PL service provider. The only exception is in the case of the generalized bell-shaped membership function, where the cumulative error is equal to 3.0784. When it comes to the empirical implementation of the proposed models, in the case of crisp input values, the TOPSIS should be used, while in the case of imprecise input data, the proposed FIS structure is a convenient choice.

6 Conclusion and future research directions

The dissertation has addressed the 3PL provider selection problem. To assist in decision-making, the implementation of fuzzy logic combined with the multi-criteria analysis methods is proposed.

The main problem is divided into four phases and the following results were obtained:

In the first phase, a distribution-concept selection problem is considered; In other words, it was necessary to decide whether the company needs to invest in its own fleet of vehicles or to engage the 3PL service provider. By applying the ARAS multi-criteria decision-making method and taking into consideration the economic, environmental, social as well as technical criterion, it was established that the distribution concept using 3PL service providers (Alternative 2 = 0.929) is a better solution for the company who considers distribution activities. The same alternative is confirmed as a better one by applying the TOPSIS method, with the preference of 0.6088.

After deciding about the distribution concept, the second phase has considered the 3PL provider evaluation and selection problem. The second-phase started by identifying the criteria for the 3PL provider evaluation and selection as well as determining its importance. To identify the criteria, an extensive review of the scientific literature, as well as experts' opinions are taken into consideration. To obtain an influential relationship between criteria, the Fuzzy-AHP method is used. At the end of the second phase of the model, the following conclusion was reached: five criteria such as price, delivery, safety, technology level, and social responsibility were established and their importance is obtained. The highest importance is assigned to the price (0.5148). The second place by importance is assigned to delivery (0.1211). The criterion of safety was at third place (0.1951), while the technology level (0.0470), as well as social responsibility (0.0310) were evaluated with less importance.

The obtained criteria weights are further used in the third phase, where the TOPSIS method is applied. The TOPSIS method was used to rank the 3PL service providers among 25 of them. As a result of the TOPSIS method, it was shown that the 3PL-23 was the best possible alternative with the preference of 0.9011. After the sensitivity analysis was conducted on the TOPSIS, it was concluded that the most stable criteria are price, delivery, and technology level.

The main contribution of the doctoral dissertation (besides the first phase) may be found in the fourth phase. In this phase, a decision-making tool for 3PL provider selection is designed as a FIS structure, where inputs are the previously defined criteria (price, delivery, safety, technology and social responsibility) and output is a preference for 3PL selection. The fuzzy rules are generated based on the collected empirical data, preferences obtained by the TOPSIS method and expert opinion using Wang-Mendel's method. The proposed tool is particularly suitable when input data are not crisp values, but they are given descriptively through the linguistic statements. The result of the proposed FIS showed the 3PL-23 as the best possible alternative.

When it comes to the final results, it may be concluded that both methods, the TOPSIS method, and the Fuzzy Inference System (FIS) gave the same results. However, the main advantage of the methodology proposed in the dissertation reflects the fact that preferences for choosing the best alternative can be obtained based on insufficiently precise input data, i.e. input data are given throughout linguistic statements within given numerical intervals. Unlike the proposed methodology, the TOPSIS method only shows the results of the crisp input values of the criteria.

Therefore, the proposed FIS structure may be implemented in practice, particularly in the case where there is no concrete numerical input data, but they are, partially or completely, given descriptively, through linguistic statements. In the case of crisp input values, the implementation of TOPSIS would be sufficient. The introduced decision-making tool could have widespread usage in all related MCDM logistics problems.

There are two practical as well as two methodological contributions in the dissertation field. When it comes to practical contributions, the Freight Distribution Concept (FDC) Selection in terms of outsourcing (need for 3PL service providers) is provided and can help the company to make a decision. The second practical contribution is related to the Third-Party Logistics (3PL) provider evaluation and selection process.

Regarding the methodological contribution, the two most important ones can be pointed out: 1) for the first time, the ARAS method is applied to solve the Freight Distribution

Concept (FDC) selection problem in the field of 3PL logistics. The main advantage of the ARAS method for the FDC selection problem reflects the fact that it can help us decide about the needs for the 3PL services; 2) the original fuzzy logic methodology is proposed to solve the 3PL evaluation and selection problem.

In the end, it may be concluded that the individual tasks of the main objective of the dissertation were completed. Such tasks were: 1) to analyze the current situation in the field of third-party logistics (3PL); 2) to determine the possibility of improvement in the field of 3PL evaluation and selection; 3) to develop a new preference model for the 3PL provider selection.

When it comes to the future research, there are the following directions: 1) to adjust the proposed FIS by optimizing it through minimizing the cumulative error in describing the empirical data and by harmonizing the final decision with TOPSIS; 2) to test the proposed methodology on different samples would be of particular interest; 3) to overcome the limitation of the application of the methodology to the illustrative example, it will be of particular interest to apply the proposed methodology to the real-life study; 4) to adjust the methodology in the picture fuzzy environment; 5) to compare the proposed methodology with the other multi-criteria decision-making methods.

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List of Appendices

Appendix A

CRITERIA	PRICE	DELIVERY	SAFETY	TECHNOLOGY LEVEL	SOCIAL RESPONSIBILITY
PRICE	(1,1,1)	(4,5,6)	(3,4,5)	(6,7,8)	(9,9,9)
DELIVERY	(1/6, 1/5, 1/4)	(1,1,1)	(1,2,3)	(4,5,6)	(6,7,8)
SAFETY	(1/5, 1/4, 1/3)	(1/3, 1/2, 1/1)	(1,1,1)	(6,7,8)	(9,9,9)
TECHNOLOGY LEVEL	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/8, 1/7, 1/6)	(1,1,1)	(1,2,3)
SOCIAL RESPONSIBILITY	(1/9, 1/9, 1/9)	(1/8, 1/7, 1/6)	(1/9, 1/9, 1/9)	(1/3, 1/2, 1/1)	(1,1,1)

FUZZIFIED PAIRWISE COMARISON MATRIX						FUZZY GEOMETRIC MEAN VALUE
CRITERIA	PRICE	DELIVERY	SAFETY	TECHNOLOGY LEVEL	SOCIAL RESPONSIBILITY	
PRICE	(1,1,1)	(4,5,6)	(3,4,5)	(6,7,8)	(9,9,9)	r1 (3.65, 4.17, 4.64)
DELIVERY	(0.16, 0.20, 0.25)	(1,1,1)	(1,2,3)	(4,5,6)	(6,7,8)	r2 (1.31, 1.70, 2.05)
SAFETY	(0.20, 0.25, 0.33)	(0.33, 0.5, 1)	(1,1,1)	(6,7,8)	(9,9,9)	r3 (1.29, 1.52, 1.88)
TECHNOLOGY LEVEL	(0.125, 0.143, 0.167)	(0.167, 0.20, 0.25)	(0.125, 0.148, 0.167)	(1,1,1)	(1,2,3)	r4 (0.3041, 0.3822, 0.4609)
SOCIAL RESPONSIBILITY	(0.11, 0.11, 0.11)	(0.125, 0.143, 0.167)	(0.11, 0.11, 0.11)	(0.33, 0.5, 1)	(1,1,1)	r5 (0.2185, 0.2439, 0.2889)

FUZZY GEOMETRIC MEAN VALUE	Wi=ri*(r1+r2+...+rn)^(-1)	i=1...5				
r1 (3.65, 4.17, 4.64)	(r1+r2+r3+r4+r5)= (3.65+1.31+1.29+0.3041+0.2185, 4.17+1.70+1.52+0.3822+0.2439, 4.64+2.05+1.88+0.4609+0.2889) = (6.7726, 8.0161, 9.3198)= (l,m,u)					
r2 (1.31, 1.70, 2.05)	(r1+r2+...+r5)^(-1) = (1/u, 1/m, 1/l)	(1/9.3198, 1/8.0161, 1/6.7726) =	(0.1072, 0.1247, 0.1476)			
r3 (1.29, 1.52, 1.88)						
r4 (0.3041, 0.3822, 0.4609)				Center of Area	Wi = (l+m+u)/3	
r5 (0.2185, 0.2439, 0.2889)		FUZZY WEIGHTS WFi	FUZZY WEIGHTS WFi	FUZZY WEIGHTS WFi	Wi	Normalised and final weights
		WF1= r1*(6.7726, 8.0161, 9.3198)^-1	WF1=(3.65, 4.17, 4.64)*(1/9.3198	(0.3913, 0.52, 0.6848)	0,532	0,5148
		WF2= r2*(6.7726, 8.0161, 9.3198)^-1	WF2=(1.31, 1.70, 2.05)*(1/9.3198	(0.1404,0.2119, 0.3026)	0,2182	0,2111
		WF3= r3*(6.7726, 8.0161, 9.3198)^-1	WF3=(1.29, 1.52, 1.88)*(1/9.3198	(0.1382, 0.1895, 0.2774)	0,2017	0,1951
		WF4= r4*(6.7726, 8.0161, 9.3198)^-1	WF4=(0.3041, 0.3822, 0.4609)*(1	(0.0325, 0.0476, 0.0680)	0,0493	0,047
		WF5= r5*(6.7726, 8.0161, 9.3198)^-1	WF5=(0.2185, 0.2439, 0.2889)*(1/	(0.0234, 0.0304, 0.0426)	0,0321	0,031

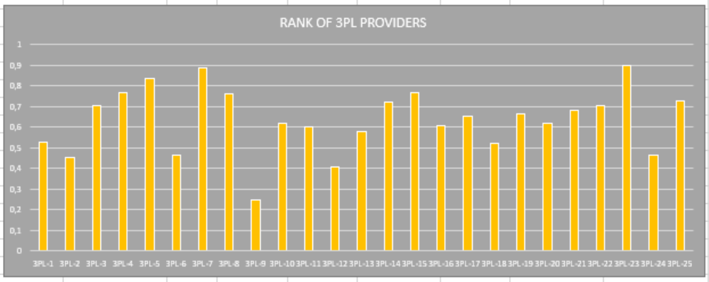
Fig. A1. Obtaining criteria weights using FUZZY-AHP method

Appendix B

Topsis method for the selection of supplier					
	Price	Delivery	Safety	Technology level	Social Responsibility
3PL-1	0,95	99,98	8	10	9
3PL-2	0,96	89,88	8	9	10
3PL-3	0,94	99,54	9	9	10
3PL-4	0,95	99,34	10	9	9
3PL-5	0,93	99,84	10	9	8
3PL-6	0,97	99,62	8	8	9
3PL-7	0,91	98,93	10	8	10
3PL-8	0,95	98,96	10	9	8
3PL-9	0,98	99,74	6	10	8
3PL-10	0,97	99,23	9	9	9
3PL-11	0,91	99,12	8	10	10
3PL-12	0,92	98,96	7	8	8
3PL-13	0,96	88,85	9	7	9
3PL-14	0,95	97,96	10	6	10
3PL-15	0,92	99,66	9	10	10
3PL-16	0,97	98,56	9	8	10
3PL-17	0,94	89,91	9	9	9
3PL-18	0,94	99,95	8	8	8
3PL-19	0,98	97,54	10	8	9
3PL-20	0,96	98,33	9	7	10
3PL-21	0,97	99,44	10	7	8
3PL-22	0,93	97,33	9	8	8
3PL-23	0,9	99,94	10	8	10
3PL-24	0,98	98,89	8	10	9
3PL-25	0,96	97,95	10	10	7
SQUARE	4,7414	489,7471	44,9110	43,1509	45,2217

Normalisation					
	Price	Delivery	Safety	Technology level	Social Responsibility
3PL-1	0,2004	0,2041	0,1781	0,2317	0,1990
3PL-2	0,2025	0,1835	0,1781	0,2086	0,2211
3PL-3	0,1983	0,2032	0,2004	0,2086	0,2211
3PL-4	0,2004	0,2028	0,2227	0,2086	0,1990
3PL-5	0,1961	0,2039	0,2227	0,2086	0,1769
3PL-6	0,2046	0,2034	0,1781	0,1854	0,1990
3PL-7	0,1919	0,2020	0,2227	0,1854	0,2211
3PL-8	0,2004	0,2021	0,2227	0,2086	0,1769
3PL-9	0,2067	0,2037	0,1336	0,2317	0,1769
3PL-10	0,2046	0,2026	0,2004	0,2086	0,1990
3PL-11	0,1919	0,2024	0,1781	0,2317	0,2211
3PL-12	0,1940	0,2021	0,1559	0,1854	0,1769
3PL-13	0,2025	0,1814	0,2004	0,1622	0,1990
3PL-14	0,2004	0,2000	0,2227	0,1390	0,2211
3PL-15	0,1940	0,2035	0,2004	0,2317	0,2211
3PL-16	0,2046	0,2012	0,2004	0,1854	0,2211
3PL-17	0,1983	0,1836	0,2004	0,2086	0,1990
3PL-18	0,1983	0,2041	0,1781	0,1854	0,1769
3PL-19	0,2067	0,1992	0,2227	0,1854	0,1990
3PL-20	0,2025	0,2008	0,2004	0,1622	0,2211
3PL-21	0,2046	0,2030	0,2227	0,1622	0,1769
3PL-22	0,1961	0,1987	0,2004	0,1854	0,1769
3PL-23	0,1898	0,2041	0,2227	0,1854	0,2211
3PL-24	0,2067	0,2019	0,1781	0,2317	0,1990
3PL-25	0,2025	0,2000	0,2227	0,2317	0,1548
Weights	0,5148	0,2111	0,1951	0,0479	0,0311

Weighted Decision Making					
	Price	Delivery	Safety	Technology level	Social Responsibility
3PL-1	0,1031	0,0431	0,0348	0,0111	0,0062
3PL-2	0,1042	0,0387	0,0348	0,0100	0,0069
3PL-3	0,1021	0,0429	0,0391	0,0100	0,0069
3PL-4	0,1031	0,0428	0,0434	0,0100	0,0062
3PL-5	0,1010	0,0430	0,0434	0,0100	0,0055
3PL-6	0,1053	0,0429	0,0348	0,0089	0,0062
3PL-7	0,0988	0,0426	0,0434	0,0089	0,0069
3PL-8	0,1031	0,0427	0,0434	0,0100	0,0055
3PL-9	0,1064	0,0430	0,0261	0,0111	0,0055
3PL-10	0,1053	0,0428	0,0391	0,0100	0,0062
3PL-11	0,0988	0,0427	0,0348	0,0111	0,0069
3PL-12	0,0999	0,0427	0,0304	0,0089	0,0055
3PL-13	0,1042	0,0383	0,0391	0,0078	0,0062
3PL-14	0,1031	0,0422	0,0434	0,0067	0,0069
3PL-15	0,0999	0,0430	0,0391	0,0111	0,0069
3PL-16	0,1053	0,0425	0,0391	0,0089	0,0069
3PL-17	0,1021	0,0388	0,0391	0,0100	0,0062
3PL-18	0,1021	0,0431	0,0348	0,0089	0,0055
3PL-19	0,1064	0,0420	0,0434	0,0089	0,0062
3PL-20	0,1042	0,0424	0,0391	0,0078	0,0069
3PL-21	0,1053	0,0429	0,0434	0,0078	0,0055
3PL-22	0,1010	0,0420	0,0391	0,0089	0,0055
3PL-23	0,0977	0,0431	0,0434	0,0089	0,0069
3PL-24	0,1064	0,0426	0,0348	0,0111	0,0062
3PL-25	0,1042	0,0422	0,0434	0,0111	0,0048
	MIN	MAX	MAX	MAX	MAX
A+	0,0977	0,0431	0,0434	0,0111	0,0069
A-	0,1064	0,0383	0,0261	0,0067	0,0048



THE DISTANCE FROM AN IDEAL AND ANTI-IDEAL SOLUTION					RANK - Ci
S1+	0,0103	S1-	0,0114	3PL-1	0,526848583
S2+	0,0118	S2-	0,0098	3PL-2	0,454332582
S3+	0,0062	S3-	0,0150	3PL-3	0,706175335
S4+	0,0056	S4+	0,0186	3PL-4	0,768904514
S5+	0,0037	S5+	0,0191	3PL-5	0,837597297
S6+	0,0118	S6+	0,0102	3PL-6	0,465326324
S7+	0,0025	S7+	0,0197	3PL-7	0,886847368
S8+	0,0057	S8+	0,0185	3PL-8	0,763862924
S9+	0,0195	S9+	0,0065	3PL-9	0,250174319
S10+	0,0089	S10+	0,0143	3PL-10	0,617254992
S11+	0,0088	S11+	0,0133	3PL-11	0,602752025
S12+	0,0135	S12+	0,0093	3PL-12	0,407240114
S13+	0,0098	S13+	0,0133	3PL-13	0,576495834
S14+	0,0071	S14+	0,0182	3PL-14	0,720602053
S15+	0,0049	S15+	0,0161	3PL-15	0,767752482
S16+	0,0091	S16+	0,0141	3PL-16	0,608366263
S17+	0,0076	S17+	0,0142	3PL-17	0,650504254
S18+	0,0101	S18+	0,0111	3PL-18	0,52404072
S19+	0,0091	S19+	0,0180	3PL-19	0,664947905
S20+	0,0085	S20+	0,0140	3PL-20	0,621605098
S21+	0,0084	S21+	0,0180	3PL-21	0,682005209
S22+	0,0061	S22+	0,0148	3PL-22	0,706580437
S23+	0,0022	S23+	0,0202	3PL-23	0,901125432
S24+	0,0123	S24+	0,0108	3PL-24	0,466379432
S25+	0,0069	S25+	0,0185	3PL-25	0,728514258
				The best 3PL is	0,9011

Fig. B1. Obtaining the rank of 3PL service provider using TOPSIS method

Weights			New Weights, if the **PRICE** is variabile																		
0,5148	1.	PRICE	0,6148	0,7148	0,8148	0,9148	0,4148	0,3148	0,3648	0,4248	0,4348	0,4048	0,3948	0,3848	0,3748	0,2148	0,1648	0,2048	0,1948	0,1848	0,1748
0,2111	2.	DELIVERY	0,1676	0,1241	0,0806	0,0371	0,2546	0,2981	0,2764	0,2503	0,2459	0,2590	0,2633	0,2677	0,2720	0,3416	0,3634	0,3460	0,3503	0,3547	0,3590
0,1951	3.	SAFETY	0,1549	0,1147	0,0745	0,0343	0,2353	0,2755	0,2554	0,2313	0,2273	0,2393	0,2434	0,2474	0,2514	0,3157	0,3358	0,3198	0,3238	0,3278	0,3318
0,0479	4.	TECHNOLOGY	0,0380	0,0282	0,0183	0,0084	0,0578	0,0676	0,0627	0,0568	0,0558	0,0588	0,0597	0,0607	0,0617	0,0775	0,0825	0,0785	0,0795	0,0805	0,0815
0,0311	5.	SOCIAL RESP.	0,0247	0,0183	0,0119	0,0055	0,0375	0,0439	0,0407	0,0369	0,0362	0,0382	0,0388	0,0394	0,0401	0,0503	0,0535	0,0510	0,0516	0,0523	0,0529
			1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
			3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-4	3PL-4	3PL-4	3PL-4	3PL-4	3PL-4

0,1	0,2	0,3	0,4	-0,1	-0,2	-0,15	-0,09	-0,08	-0,1100	-0,1200	-0,1300	-0,1400	-0,3	-0,35	-0,31	-0,32	-0,33	-0,34
-0,0435	-0,0870	-0,1305	-0,1740	0,0435	0,0870	0,0653	0,0392	0,03481	0,0479	0,0522	0,0566	0,0609	0,13052	0,1523	0,1349	0,1392	0,1436	0,1479
-0,0402	-0,0804	-0,1206	-0,1608	0,0402	0,0804	0,0603	0,0362	0,03217	0,0442	0,0483	0,0523	0,0563	0,1206	0,1407	0,1247	0,1287	0,1327	0,1367
-0,0099	-0,0197	-0,0296	-0,0395	0,0099	0,0197	0,0148	0,0089	0,0079	0,0109	0,0118	0,0128	0,0138	0,0296	0,0346	0,0306	0,0316	0,0326	0,0336
-0,0064	-0,0128	-0,0192	-0,0256	0,0064	0,0128	0,0096	0,0058	0,00513	0,0071	0,0077	0,0083	0,0090	0,0192	0,0224	0,0199	0,0205	0,0212	0,0218
3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-4	3PL-4	3PL-4	3PL-4	3PL-4	3PL-4

	Weights		New Weights, if the **DELIVERY** is variable																		
DELIVERY	0,2111	2.	DELIVERY	0,3111	0,4111	0,5111	0,6111	0,7111	0,8111	0,1111	0,1211	0,1311	0,1411	0,1511	0,1611	0,1711	0,1811	0,1911	0,2011	0,0111	0,0011
PRICE	0,5148	1.	PRICE	0,4495	0,3843	0,3190	0,2538	0,1885	0,1233	0,5801	0,5735	0,5670	0,5605	0,5540	0,5474	0,5409	0,5344	0,5279	0,5213	0,6453	0,6518
SAFETY	0,1951	3.	SAFETY	0,1704	0,1456	0,1209	0,0962	0,0714	0,0467	0,2198	0,2174	0,2149	0,2124	0,2099	0,2075	0,2050	0,2025	0,2000	0,1976	0,2446	0,2470
TECHNOLOGY	0,0479	4.	TECHNOLOGY	0,0418	0,0358	0,0297	0,0236	0,0175	0,0115	0,0540	0,0534	0,0528	0,0522	0,0515	0,0509	0,0503	0,0497	0,0491	0,0485	0,0600	0,0607
SOCIAL RESPONS	0,0311	5.	SOCIAL RESP.	0,0272	0,0232	0,0193	0,0153	0,0114	0,0074	0,0350	0,0346	0,0343	0,0339	0,0335	0,0331	0,0327	0,0323	0,0319	0,0315	0,0390	0,0394
			SUMA Wi	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

θ1 (Delivery)	0,1000	0,2000	0,3000	0,4000	0,5000	0,6000	-0,1000	-0,0900	-0,0800	-0,0700	-0,0600	-0,0500	-0,0400	-0,0300	-0,0200	-0,0100	-0,2000	-0,2100
θ2 (Price)	-0,0653	-0,1305	-0,1958	-0,2610	-0,3263	-0,3915	0,0653	0,0587	0,0522	0,0457	0,0392	0,0326	0,0261	0,0196	0,0131	0,0065	0,1305	0,1370
θ3 (Safety)	-0,0247	-0,0495	-0,0742	-0,0989	-0,1237	-0,1484	0,0247	0,0223	0,0198	0,0173	0,0148	0,0124	0,0099	0,0074	0,0049	0,0025	0,0495	0,0519
θ4(Technology)	-0,0061	-0,0121	-0,0182	-0,0243	-0,0304	-0,0364	0,0061	0,0055	0,0049	0,0043	0,0036	0,0030	0,0024	0,0018	0,0012	0,0006	0,0121	0,0128
θ5(Social)	-0,0039	-0,0079	-0,0118	-0,0158	-0,0197	-0,0237	0,0039	0,0035	0,0032	0,0028	0,0024	0,0020	0,0016	0,0012	0,0008	0,0004	0,0079	0,0083
The Best 3PL	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23

	Weights			New Weights, if the **SAFETY** is variable															
SAFETY	0,1951	3.	SAFETY	0,2951	0,3951	0,4951	0,5951	0,6951	0,2451	0,2051	0,0951	0,0100	0,0851	0,0751	0,0651	0,0551	0,0451	0,0251	0,0351
DELIVERY	0,2111	2.	DELIVERY	0,1849	0,1586	0,1324	0,1062	0,0800	0,1980	0,2085	0,2373	0,2596	0,2399	0,2426	0,2452	0,2478	0,2504	0,2557	0,2531
PRICE	0,5148	1.	PRICE	0,4508	0,3869	0,3229	0,2590	0,1950	0,4828	0,5084	0,5788	0,6332	0,5852	0,5915	0,5979	0,6043	0,6107	0,6235	0,6171
TECHNOLOGY	0,0479	4.	TECHNOLOGY	0,0419	0,0360	0,0300	0,0241	0,0181	0,0449	0,0473	0,0539	0,0589	0,0544	0,0550	0,0556	0,0562	0,0568	0,0580	0,0574
SOCIAL RESPONS	0,0311	5.	SOCIAL RESP.	0,0272	0,0234	0,0195	0,0156	0,0118	0,0292	0,0307	0,0350	0,0383	0,0354	0,0357	0,0361	0,0365	0,0369	0,0377	0,0373
			SUMA Wi	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

θ1 (Safety)	0,1000	0,2000	0,3000	0,4000	0,5000	0,0500	0,0100	-0,1000	-0,1851	-0,1100	-0,1200	-0,1300	-0,1400	-0,1500	-0,1700	-0,1600
θ2 (Delivery)	-0,0262	-0,0525	-0,0787	-0,1049	-0,1311	-0,0131	-0,0026	0,0262	0,0485	0,0288	0,0315	0,0341	0,0367	0,0393	0,0446	0,0420
θ3 (Price)	-0,0640	-0,1279	-0,1919	-0,2558	-0,3198	-0,0320	-0,0064	0,0640	0,1184	0,0704	0,0767	0,0831	0,0895	0,0959	0,1087	0,1023
θ4(Technology)	-0,0060	-0,0119	-0,0179	-0,0238	-0,0298	-0,0030	-0,0006	0,0060	0,0110	0,0065	0,0071	0,0077	0,0083	0,0089	0,0101	0,0095
θ5(Social)	-0,0039	-0,0077	-0,0116	-0,0155	-0,0193	-0,0019	-0,0004	0,0039	0,0072	0,0043	0,0046	0,0050	0,0054	0,0058	0,0066	0,0062
The Best 3PL	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-11	3PL-23	3PL-23	3PL-23	3PL-23	3PL-11	3PL-11	3PL-11

	Weights			New Weights, if the **TECHNOLOGY** is variable																						
TECHNOLOGY	0,0479	4.	TECHNOLOGY	0,1479	0,2479	0,3479	0,4479	0,5479	0,6479	0,7479	0,8479	0,9479	0,9979	0,1379	0,0379	0,0279	0,0179	0,0129	0,1279	0,0979	0,0679	0,0879	0,1079	0,1179	0,0579	0,0779
SAFETY	0,1951	3.	SAFETY	0,1746	0,1541	0,1336	0,1131	0,0926	0,0722	0,0517	0,0312	0,0107	0,0004	0,1767	0,1971	0,1992	0,2012	0,2023	0,1787	0,1849	0,1910	0,1869	0,1828	0,1808	0,1931	0,1890
DELIVERY	0,2111	2.	DELIVERY	0,1889	0,1668	0,1446	0,1224	0,1002	0,0781	0,0559	0,0337	0,0116	0,0005	0,1911	0,2133	0,2155	0,2178	0,2189	0,1934	0,2000	0,2067	0,2022	0,1978	0,1956	0,2089	0,2044
PRICE	0,5148	1.	PRICE	0,4607	0,4067	0,3526	0,2985	0,2445	0,1904	0,1363	0,0822	0,0282	0,0011	0,4661	0,5202	0,5256	0,5310	0,5337	0,4715	0,4878	0,5040	0,4932	0,4824	0,4770	0,5094	0,4986
SOCIAL RESP.	0,0311	5.	SOCIAL RESP.	0,0278	0,0246	0,0213	0,0180	0,0148	0,0115	0,0082	0,0050	0,0017	0,0001	0,0282	0,0314	0,0318	0,0321	0,0322	0,0285	0,0295	0,0304	0,0298	0,0291	0,0288	0,0308	0,0301
			SUMA	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

TECHNOLOGY	0,1000	0,2000	0,3000	0,4000	0,5000	0,6000	0,7000	0,8000	0,9000	0,9500	0,0900	-0,0100	-0,0200	-0,0300	-0,0350	0,0800	0,0500	0,0200	0,0400	0,0600	0,0700	0,0100	0,0300
SAFETY	-0,0205	-0,0410	-0,0615	-0,0820	-0,1025	-0,1229	-0,1434	-0,1639	-0,1844	-0,1947	-0,0184	0,0020	0,0041	0,0061	0,0072	-0,0164	-0,0102	-0,0041	-0,0082	-0,0123	-0,0143	-0,0020	-0,0061
DELIVERY	-0,0222	-0,0443	-0,0665	-0,0887	-0,1109	-0,1330	-0,1552	-0,1774	-0,1995	-0,2106	-0,0200	0,0022	0,0044	0,0067	0,0078	-0,0177	-0,0111	-0,0044	-0,0089	-0,0133	-0,0155	-0,0022	-0,0067
PRICE	-0,0541	-0,1081	-0,1622	-0,2163	-0,2703	-0,3244	-0,3785	-0,4326	-0,4866	-0,5137	-0,0487	0,0054	0,0108	0,0162	0,0189	-0,0433	-0,0270	-0,0108	-0,0216	-0,0324	-0,0378	-0,0054	-0,0162
SOCIAL RESP.	-0,0033	-0,0065	-0,0098	-0,0131	-0,0163	-0,0196	-0,0229	-0,0261	-0,0294	-0,0310	-0,0029	0,0003	0,0007	0,0010	0,0011	-0,0026	-0,0016	-0,0007	-0,0013	-0,0020	-0,0023	-0,0003	-0,0010
The Best 3PL	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-15	3PL-23	3PL-23	3PL-23	3PL-23	3PL-5	3PL-5	3PL-23	3PL-23	3PL-5	3PL-5	3PL-23	3PL-23

	Weights			New weights if the **SOCIAL RESPONSIBILITY** is variable																						
SOCIAL RESP.	0,0311	5.	SOCIAL RESP.	0,0011	0,0111	0,0211	0,0411	0,0511	0,0611	0,0711	0,0811	0,0911	0,1011	0,1111	0,1211	0,1311	0,2311	0,3311	0,4311	0,5311	0,6311	0,7311	0,8311	0,9311	0,9811	0,9911
TECHNOLOGY	0,0479	4.	TECHNOLOGY	0,0494	0,0489	0,0484	0,0474	0,0469	0,0464	0,0459	0,0454	0,0449	0,0444	0,0439	0,0435	0,0430	0,0380	0,0331	0,0281	0,0232	0,0182	0,0133	0,0083	0,0034	0,0009	0,0004
SAFETY	0,1951	3.	SAFETY	0,2011	0,1991	0,1971	0,1931	0,1911	0,1891	0,1870	0,1850	0,1830	0,1810	0,1790	0,1770	0,1750	0,1548	0,1347	0,1146	0,0944	0,0743	0,0541	0,0340	0,0139	0,0038	0,0018
DELIVERY	0,2111	2.	DELIVERY	0,2176	0,2155	0,2133	0,2089	0,2067	0,2046	0,2024	0,2002	0,1980	0,1958	0,1937	0,1915	0,1893	0,1675	0,1457	0,1239	0,1022	0,0804	0,0586	0,0368	0,0150	0,0041	0,0019
PRICE	0,5148	1.	PRICE	0,5307	0,5254	0,5201	0,5095	0,5042	0,4989	0,4935	0,4882	0,4829	0,4776	0,4723	0,4670	0,4617	0,4085	0,3554	0,3023	0,2491	0,1960	0,1429	0,0897	0,0366	0,0100	0,0047
			SUMA	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

SOCIAL RESP.	-0,0300	-0,0200	-0,0100	0,0100	0,0200	0,0300	0,0400	0,0500	0,0600	0,0700	0,0800	0,0900	0,1000	0,2000	0,3000	0,4000	0,5000	0,6000	0,7000	0,8000	0,9000	0,9500	0,9600
TECHNOLOGY	0,0015	0,0010	0,0005	-0,0005	-0,0010	-0,0015	-0,0020	-0,0025	-0,0030	-0,0035	-0,0040	-0,0044	-0,0049	-0,0099	-0,0148	-0,0198	-0,0247	-0,0297	-0,0346	-0,0396	-0,0445	-0,0470	-0,0475
SAFETY	0,0060	0,0040	0,0020	-0,0020	-0,0040	-0,0060	-0,0081	-0,0101	-0,0121	-0,0141	-0,0161	-0,0181	-0,0201	-0,0403	-0,0604	-0,0805	-0,1007	-0,1208	-0,1410	-0,1611	-0,1812	-0,1913	-0,1933
DELIVERY	0,0065	0,0044	0,0022	-0,0022	-0,0044	-0,0065	-0,0087	-0,0109	-0,0131	-0,0153	-0,0174	-0,0196	-0,0218	-0,0436	-0,0654	-0,0872	-0,1089	-0,1307	-0,1525	-0,1743	-0,1961	-0,2070	-0,2092
PRICE	0,0159	0,0106	0,0053	-0,0053	-0,0106	-0,0159	-0,0213	-0,0266	-0,0319	-0,0372	-0,0425	-0,0478	-0,0531	-0,1063	-0,1594	-0,2125	-0,2657	-0,3188	-0,3719	-0,4251	-0,4782	-0,5048	-0,5101
The Best 3PL	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23	3PL-23- 3PL-7

Fig. B2 Sensitivity analysis on TOPSIS method

Appendix C

	E1	E2	E3	E4	E5	Experts' evaluation	WEIGHTS
(C11) Vehicle procurement cost	5	5	3	4	5	22	0,0661
(C12) Vehicle maintenance cost	5	5	5	4	5	24	0,0721
(C13) Time of return on investme	3	3	3	5	3	17	0,0511
(C14) Financial performance	4	4	4	4	4	20	0,0601
(C21) Air pollution	4	2	5	3	4	18	0,0541
(C22) Noise pollution	4	4	4	3	4	19	0,0571
(C23) Effect on public health	4	4	5	4	4	21	0,0631
(C24) Energy consumption	4	4	4	4	4	20	0,0601
(C31) Social reputation	4	4	4	5	5	22	0,0661
(C32) Brand building	5	5	5	5	5	25	0,0751
(C33) Enterprise culture construc	5	5	5	4	4	23	0,0691
(C34) Job opportunities	5	5	2	2	2	16	0,0480
(C41) Quality of service	5	5	5	5	5	25	0,0751
(C42) Flexibility	4	4	4	5	4	21	0,0631
(C43) Vehicle reliability index	3	3	4	5	4	19	0,0571
(C44) Parking space utilization ir	4	4	4	5	4	21	0,0631
						333	1

	E1	E2	E3	E4	E5	SUM BY ROWS	WEIGHTS
Economic	5	5	5	5	5	25	0,2841
Environmental	3	4	5	4	5	21	0,2386
Social	4	4	5	3	4	20	0,2273
Technical	5	4	4	5	4	22	0,2500
						88	

ALTERNATIVE 1	E1	E2	E3	E4	E5	Experts' evaluation
(C11) Vehicle procurement cost	5	5	3	4	5	4,4
(C12) Vehicle maintenance cost	5	5	5	4	5	4,8
(C13) Time of return on investment	3	3	3	5	3	3,4
(C14) Financial performance	4	4	4	4	4	4
(C21) Air pollution	4	2	5	3	4	3,6
(C22) Noise pollution	4	4	4	3	4	3,8
(C23) Effect on public health	4	4	5	4	4	4,2
(C24) Energy consumption	4	4	4	4	4	4
(C31) Social reputation	4	4	4	5	5	4,4
(C32) Brand building	5	5	5	5	5	5
(C33) Enterprise culture construction	5	5	5	4	4	4,6
(C34) Job opportunities	5	5	2	2	2	3,2
(C41) Quality of service	5	5	5	5	5	5
(C42) Flexibility	4	4	4	5	4	4,2
(C43) Vehicle reliability index	3	3	4	5	4	3,8
(C44) Parking space utilization index	4	4	4	5	4	4,2

ALTERNATIVE 2	E1	E2	E3	E4	E5	Experts' evaluation
(C11) Vehicle procurement cost	2	2	2	1	1	1,6
(C12) Vehicle maintenance cost	2	2	2	1	1	1,6
(C13) Time of return on investment	2	2	2	3	2	2,2
(C14) Financial performance	3	3	3	4	5	3,6
(C21) Air pollution	4	4	4	3	4	3,8
(C22) Noise pollution	4	4	3	2	3	3,2
(C23) Effect on public health	4	4	4	4	5	4,2
(C24) Energy consumption	4	4	4	3	5	4
(C31) Social reputation	4	4	4	4	5	4,2
(C32) Brand building	4	4	4	5	5	4,4
(C33) Enterprise culture construction	4	4	4	5	5	4,4
(C34) Job opportunities	4	4	3	3	2	3,2
(C41) Quality of service	5	5	5	5	5	5
(C42) Flexibility	4	4	4	5	5	4,4
(C43) Vehicle reliability index	5	5	5	4	4	4,6
(C44) Parking space utilization index	2	2	1	1	1	1,4

Fig. C1. Experts' assessment

TABLE 1 - Initial DM matrix

CRITERIA	Economic				Environmental				Social				Technical				
SUB-CRITERIA	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	
0 - OPTIMAL VALUE	1,6	1,6	2,2	3,6	3,6	3,2	4,2	4	4,4	5	4,6	3,2	5	4,4	4,6	4,2	
A1	4,4	4,8	3,4	4	3,6	3,8	4,2	4	4,4	5	4,6	3,2	5	4,2	3,8	4,2	
A2	1,6	1,6	2,2	3,6	3,8	3,2	4,2	4	4,2	4,4	4,4	3,2	5	4,4	4,6	1,4	
WEIGHTS	0,0661	0,0721	0,0511	0,0601	0,0541	0,0571	0,0631	0,0601	0,0661	0,0751	0,069	0,048	0,075	0,0631	0,0569	0,0631	1,0001
Type of the sub-criteria	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MIN	MAX	MAX	MAX	MAX	MAX	MAX	MAX	MAX	
SUMA	1,4773	1,4583	1,2032	0,8056	0,8187	0,8882	0,7143	5,500	13	14,4	13,6	9,6	15	13	13	9,8	

TABLE 2 - Normalization

CRITERIA	Economic				Environmental				Social				Technical			
SUB-CRITERIA	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
0 - OPTIMAL VALUE	0,4231	0,4286	0,3778	0,3448	0,3393	0,3519	0,3333	0,0455	0,3385	0,3472	0,3382	0,3333	0,3333	0,3385	0,3538	0,4286
A1	0,1538	0,1429	0,2444	0,3103	0,3393	0,2963	0,3333	0,0455	0,3385	0,3472	0,3382	0,3333	0,3333	0,3231	0,2923	0,4286
A2	0,4231	0,4286	0,3778	0,3448	0,3214	0,3519	0,3333	0,0455	0,3231	0,3056	0,3235	0,3333	0,3333	0,3385	0,3538	0,1429
WEIGHTS	0,0661	0,0721	0,0511	0,0601	0,0541	0,0571	0,0631	0,0601	0,0661	0,0751	0,069	0,048	0,075	0,0631	0,0569	0,0631

TABLE 3. Weighted DM matrix

CRITERIA	Economic				Environmental				Social				Technical					
SUB-CRITERIA	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	S	K
0 - OPTIMAL VALUE	0,0280	0,0309	0,0193	0,0207	0,0184	0,0201	0,0210	0,0027	0,0224	0,0261	0,0233	0,0160	0,0250	0,0214	0,0201	0,0270	0,3424	
A1	0,0102	0,0103	0,0125	0,0187	0,0184	0,0169	0,0210	0,0027	0,0224	0,0261	0,0233	0,0160	0,0250	0,0204	0,0166	0,0270	0,2875	0,8396
A2	0,0280	0,0309	0,0193	0,0207	0,0174	0,0201	0,0210	0,0027	0,0214	0,0229	0,0223	0,0160	0,0250	0,0214	0,0201	0,0090	0,3183	0,9295

Fig. C2. ARAS method - calculation

SUB-CRITERIA	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A1	4,4	4,8	3,4	4	3,6	3,8	4,2	4	4,4	5	4,6	3,2	5	4,2	3,8	4,2
A2	1,6	1,6	2,2	3,6	3,8	3,2	4,2	4	4,2	4,4	4,4	3,2	5	4,4	4,6	1,4
WEIGHTS	0,0661	0,0721	0,0511	0,0601	0,0541	0,0571	0,0631	0,0601	0,0661	0,0751	0,069	0,048	0,075	0,0631	0,0569	0,063

SUB-CRITERIA	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A1	0,9398	0,9487	0,8396	0,7433	0,6877	0,7649	0,7071	0,7071	0,7234	0,7507	0,7226	0,7071	0,7071	0,6905	0,6369	0,9487
A2	0,3417	0,3162	0,5433	0,6690	0,7260	0,6441	0,7071	0,7071	0,6905	0,6606	0,6912	0,7071	0,7071	0,7234	0,7710	0,3162
WEIGHTS	0,0661	0,0721	0,0511	0,0601	0,0541	0,0571	0,0631	0,0601	0,0661	0,0751	0,069	0,048	0,075	0,0631	0,0569	0,0631

SUB-CRITERIA	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}
A1	0,0621	0,0684	0,0429	0,0447	0,0372	0,0437	0,0446	0,0425	0,0478	0,0564	0,0499	0,0339	0,0530	0,0436	0,0362	0,0599
A2	0,0226	0,0228	0,0278	0,0402	0,0393	0,0368	0,0446	0,0425	0,0456	0,0496	0,0477	0,0339	0,0530	0,0456	0,0439	0,0200
IDEAL A+	0,0226	0,0228	0,0278	0,0402	0,0372	0,0368	0,0446	0,0425	0,0478	0,0564	0,0499	0,0339	0,0530	0,0456	0,0439	0,0599
A-IDEAL A-	0,0621	0,0684	0,0429	0,0447	0,0393	0,0437	0,0446	0,0425	0,0456	0,0496	0,0477	0,0339	0,0530	0,0436	0,0362	0,0200

A distance of each alternative to ideal and anti-ideal solution

S1+	0,0633	S1-	0,0406	A1	0,39119
S2+	0,0406	S2-	0,0633	A2	0,60881

Fig. C3. Applied TOPSIS in the first part

Appendix D – Fuzzy Rules

1. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

2. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is LT) and (Responsibility is MR) then (Preference is LowP)

3. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is LT) and (Responsibility is HR) then (Preference is LowP)

4. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is MT) and (Responsibility is LR) then (Preference is LowP)

5. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is MT) and (Responsibility is MR) then (Preference is LowP)

6. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is MT) and (Responsibility is HR) then (Preference is LowP)

7. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is HT) and (Responsibility is LR) then (Preference is LowP)

8. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is HT) and (Responsibility is MR) then (Preference is LowP)

9. If (Price is LP) and (Delivery is LD) and (Safety is LS) and (Technology is HT) and (Responsibility is HR) then (Preference is LowP)

10. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

11. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

12. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

13. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

14. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

15. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

16. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

17. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

18. If (Price is LP) and (Delivery is LD) and (Safety is MS) and (Technology is HT) and (Responsibility is HR) then (Preference is MedP)

19. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is LT) and (Responsibility is LR) then (Preference is MedP)

20. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

21. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

22. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

23. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

24. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

25. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

26. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

27. If (Price is LP) and (Delivery is LD) and (Safety is HS) and (Technology is HT) and (Responsibility is HR) then (Preference is MedP)

28. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

29. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is LT) and (Responsibility is MR) then (Preference is LowP)

30. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

31. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

32. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

33. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

34. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is HT) and (Responsibility is LR) then (Preference is LowP)

35. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

36. If (Price is LP) and (Delivery is MD) and (Safety is LS) and (Technology is HT) and (Responsibility is HR) then (Preference is MedP)

37. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

38. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

39. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

40. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

41. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

42. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is MT) and (Responsibility is HR) then (Preference is HighP)

43. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

44. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

45. If (Price is LP) and (Delivery is MD) and (Safety is MS) and (Technology is HT) and (Responsibility is HR) then (Preference is MedP)

46. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is LT) and (Responsibility is LR) then (Preference is MedP)

47. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

48. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

49. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

50. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is MT) and (Responsibility is MR) then (Preference is HighP)

51. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is MT) and (Responsibility is HR) then (Preference is HighP)

52. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is HT) and (Responsibility is LR) then (Preference is HighP)

53. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is HT) and (Responsibility is MR) then (Preference is HighP)

54. If (Price is LP) and (Delivery is MD) and (Safety is HS) and (Technology is HT) and (Responsibility is HR) then (Preference is HighP)

55. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

56. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

57. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

58. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

59. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is MT) and (Responsibility is MR) then (Preference is LowP)

60. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

61. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

62. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

63. If (Price is LP) and (Delivery is HD) and (Safety is LS) and (Technology is HT) and (Responsibility is HR) then (Preference is MedP)

64. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

65. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

66. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

67. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is MT) and (Responsibility is LR) then (Preference is MedP)

68. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

69. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

70. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

71. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

72. If (Price is LP) and (Delivery is HD) and (Safety is MS) and (Technology is HT) and (Responsibility is HR) then (Preference is MedP)

73. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

74. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

75. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

76. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is MT) and (Responsibility is LR) then (Preference is LowP)

77. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is MT) and (Responsibility is MR) then (Preference is HighP)

78. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is MT) and (Responsibility is HR) then (Preference is HighP)

79. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

80. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

81. If (Price is LP) and (Delivery is HD) and (Safety is HS) and (Technology is HT) and (Responsibility is HR) then (Preference is HighP)

82. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is LT) and (Responsibility is LR) then (Preference is LowP)

83. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is LT) and (Responsibility is MR) then (Preference is LowP)

84. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

85. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is MT) and (Responsibility is LR) then (Preference is LowP)

86. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

87. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

88. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is HT) and (Responsibility is LR) then (Preference is MedP)

89. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

90. If (Price is MP) and (Delivery is LD) and (Safety is LS) and (Technology is HT) and (Responsibility is HR) then (Preference is HighP)

91. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is LT) and (Responsibility is LR) then (Preference is MedP)

92. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is LT) and (Responsibility is MR) then (Preference is MedP)

93. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is LT) and (Responsibility is HR) then (Preference is MedP)

94. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is MT) and (Responsibility is LR) then (Preference is LowP)

95. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is MT) and (Responsibility is MR) then (Preference is MedP)

96. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is MT) and (Responsibility is HR) then (Preference is MedP)

97. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is HT) and (Responsibility is LR) then (Preference is LowP)

98. If (Price is MP) and (Delivery is LD) and (Safety is MS) and (Technology is HT) and (Responsibility is MR) then (Preference is MedP)

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243. If (Price is HP) and (Delivery is HD) and (Safety is HS) and (Technology is HT) and (Responsibility is HR) then (Preference is HighP)

Tab. D1. Stability testing of FIS

Trap-mf	CE	Gbell-mf	CE	Gauss-mf	CE	Gauss2mf	CE	zmf, pimf, smf	CE
0.5871	0.0603	0.5912	0.5046	0.5046	0.0222	0.5814	0.0546	0.5890	0.0622
0.6374	0.1831	0.5953	0.6122	0.6122	0.1579	0.6108	0.1565	0.6093	0.1550
0.6090	0.0971	0.6145	0.6144	0.6144	0.0917	0.5989	0.1072	0.5947	0.1114
0.7232	0.0456	0.6939	0.6039	0.6039	0.1649	0.7423	0.0265	0.7914	0.0225
0.4867	0.3508	0.6253	0.4354	0.4354	0.4022	0.4817	0.3559	0.4782	0.3593
0.5039	0.0386	0.5913	0.5652	0.5652	0.0999	0.5432	0.0780	0.5722	0.1069
0.7216	0.1652	0.7322	0.7416	0.7416	0.1452	0.7556	0.1312	0.8143	0.0725
0.4989	0.2649	0.6118	0.4340	0.4340	0.3298	0.4987	0.2651	0.4981	0.2657
0.4082	0.1580	0.5278	0.3386	0.3386	0.0885	0.4082	0.1580	0.4082	0.1580
0.5975	0.0197	0.5948	0.5690	0.5690	0.0482	0.5835	0.0337	0.5881	0.0291
0.6078	0.0051	0.6284	0.5494	0.5494	0.0533	0.5940	0.0087	0.5921	0.0106
0.4082	0.0010	0.4142	0.5091	0.5091	0.1019	0.4082	0.0010	0.4082	0.0010
0.4510	0.1254	0.4633	0.4112	0.4112	0.1653	0.4829	0.0936	0.5011	0.0754
0.5941	0.1265	0.5901	0.5891	0.5891	0.1315	0.5841	0.1365	0.5900	0.1306
0.5969	0.1708	0.6396	0.6292	0.6292	0.1385	0.5902	0.1775	0.5884	0.1793
0.7215	0.1131	0.7104	0.6857	0.6857	0.0774	0.7388	0.1304	0.7873	0.1790
0.5907	0.0597	0.5937	0.5481	0.5481	0.1024	0.5850	0.0655	0.5892	0.0613
0.4550	0.0689	0.5279	0.4225	0.4225	0.1015	0.4842	0.0398	0.5159	0.0080
0.5890	0.0759	0.5930	0.5898	0.5898	0.0751	0.5828	0.0821	0.5899	0.0750
0.6469	0.0253	0.6085	0.5936	0.5936	0.0279	0.6239	0.0024	0.6247	0.0031
0.5236	0.1584	0.4817	0.4744	0.4744	0.2076	0.5300	0.1519	0.5456	0.1364
0.4206	0.2859	0.5356	0.4240	0.4240	0.2825	0.4169	0.2897	0.4082	0.2984
0.7617	0.1394	0.7091	0.7566	0.7566	0.1445	0.7980	0.1031	0.8461	0.0550
0.5824	0.1161	0.5912	0.5046	0.5046	0.0383	0.5744	0.1081	0.5832	0.1168
0.3593	0.3691	0.3071	0.3881	0.3881	0.3404	0.3410	0.3874	0.3157	0.4128
0.6374	0.0603	0.5912	0.5046	0.5046	0.0222	0.5814	0.0546	0.5890	0.0622
$\sum CE$	3.2242		3.0784		3.5385		3.1442		3.0855